REMARKS

The final Office Action of July 6, 2009 has been carefully considered.

Claims 11-13 have been amended to insert the word "resin" which was unintentionally omitted from the previous amendment. New claims 14- 17 have been added to the application.

Claims 1 and 9 have been rejected under 35 USC 102(b) as being anticipated by Suzuki et al (US 6,129,871), while claims 2, 7 and 10-13 have been rejected under 35 USC 103(a) over Suzuki.

Suzuki et al describes a manufacturing method for a wood board. It is noted that aspen is the only wood described throughout the detailed examples provided by Suzuki et al. Suzuki et al provides no teaching as to how the manufacturing method is used for any woods other than aspen. The only disclosure by Suzuki et al relating to any wood species other than aspen is found at column 4, lines 7-13:

> The material lumber used here is not particularly limited, and a material wood or a small diameter wood from a coniferous tree, such as Japanese red pine, larch, spruce, white fir, lodgepole pine, radiata pine, cedar, slash pine, eucalyptus, acacia, albizza, southern yellow pine, yellow cedar, red cedar, pinaster, rubber tree, and the like, or from a broadleaf tree such as aspen may be suitably employed.

This paragraph provides the only mention of eucalyptus wood in Suzuki et al.

Moreover, the disclosure of Suzuki et al incorrectly categorizes eucalypt wood, demonstrating that Suzuki et al does not appreciate the particular properties of wood from eucalypts. Specifically, Suzuki et al identifies eucalyptus as an example of a type of wood from a *coniferous* tree. It is well known by those skilled in the art that coniferous trees

are *softwood* trees by definition, including species such as pine, spruce and cedar (as noted in the list of Suzuki et al). It is well known in the art that eucalyptus species are not classified as either coniferous trees or softwoods; indeed, the present application identifies eucalypts as *hardwoods*. Therefore, the skilled artisan would appreciate that the listing of eucalyptus as an example of a coniferous tree, and hence as a softwood, is simply incorrect, and it is submitted therefore that the skilled artisan would dismiss the teaching of Suzuki et al to the extent that it relates to eucalypts.

In other words, one or ordinary skill in the art would conclude that since eucalyptus species are not coniferous trees or softwoods, the wood from eucalypts would not be appropriate for use in the product disclosed by Suzuki et al, despite the mention of eucalyptus in the list. Accordingly, the identification of eucalyptus is clearly in error, and Suzuki et al does not therefore anticipate the invention.

Since no disclosure is provided by Suzuki et al to suggest that the processes would need to be adapted for different types of wood, it is submitted that Suzuki et al has merely speculatively listed a number of wood varieties that would be desirable, without providing any proof that they would actually work with the described manufacturing process. In light of this, it is submitted that the single mere mention of eucalyptus as a suitable wood does not mean that the method disclosed by Suzuki et al would be appropriate for use with wood from eucalypts.

Irrespective of the incorrect categorization of eucalypts, Suzuki et al has not provided details of how to use the wood from eucalypts, and it is further submitted that a skilled person would conclude that Suzuki et al does not provide an enabling disclosure for manufacturing a strand product using hardwood from eucalypts.

In the absence of any teaching as to how the specific

example methods could be adapted for other wood, or any description of results for other wood varieties, it is submitted that a skilled person would conclude that the method of Suzuki et al will only work using aspen wood. A skilled person would understand that it is not a trivial exercise to adapt wood board manufacturing processes to different types of wood, and would therefore come to the conclusion that the disclosed method is not applicable to wood species other than aspen. Indeed, aspen is a soft and low density variety of wood from a broadleaf tree. The manufacturing processes for pressing a high density hardwood, such as wood from a eucalyptus tree, are very different from those for softer, lower density woods such as aspen.

There are specific differences with respect to the specific manufacturing method of Suzuki et al which suggest that the method would not work with eucalypts. For example, Suzuki et al teaches a steam injection pressing process, and the particular water content of the board is considered to be particularly important in the discussion of the properties of the final product, with water content being controlled to be within 5-15%. In contrast, in the manufacture of the claimed invention the strands are dried to preferably less than 5% moisture (as described on page 3, lines 11-13 of the specification), and no moisture is added in the dry hot pressing process described on page 4, lines 11-15.

Accordingly, a new claim 14 recites that the strands used to form the product are dried to less than 5% moisture, and a new method claim 16 has been added to the application to highlight the differences in the manufacturing method used to make the strand product.

Claim 16 requires the following steps:

a) forming strands from logs of eucalypts;

b) drying the strands to less than 5% moisture;

c) adding a binder including an isocyanate resin to the

strands;

d) forming a mat with the strands which are substantially aligned and the binder; and,

e) compressing and heating the mat using a press to form the strand product.

Irrespective of the inadequate disclosure of Suzuki et al in relation to the use of eucalypts as discussed above, Suzuki et al does not disclose or suggest "drying the strands to less than 5% moisture," or "pressing and heating the mat using a press to form the strand product."

Suzuki et al teaches away from the drying step; in contrast to the method of claim 15, the manufacturing process disclosed by Suzuki et al involves several moisturizing steps. For example, Suzuki et al describes adding water to the strands before pressing to adjust the water content of the strands. This is performed by applying binder to wooden strands after the water content of the ligneous strands has first been adjusted to 5 to 20% or, alternatively, adding water to the wooden strands when applying the binder so that the water content thereof is in the range of 5 to 20% (see, for example, column 2, lines 31-40).

Furthermore, Suzuki et al uses a steam injection pressing step in which binder coated wooden strands undergo thermal compression molding and moisturizing, to obtain a molded material with a water content in the range of 5 to 15% (see column 2, lines 21-30 and column 5, lines 50-63). Suzuki et al teaches that achieving a water content in the range of 5 to 15% is *critical* to the performance and quality of the wood board product, and specifically states that controlling the moisture content is necessary to provide boards with a high level of dimensional stability and little warping.

On the other hand, the claimed method can be used to form a high strength structural strand product using a pressing process that does not involve the addition of moisture.

Turning to the obviousness rejection of claims 2, 7 and 10-13 over Suzuki et al, the Office Action has acknowledged that Suzuki et al does not explicitly describe the features of claims 2, 7 and 10-13, but has asserted that the claimed features are inherently taught by Suzuki et al or would otherwise be obvious to a skilled person.

However, it is submitted that features of at least claim 13 are not inherently taught or obvious. Claim 13 recites that the strands are formed from plantation trees having an age between 8 years and 12 years.

Suzuki et al does not provide any disclosure relating to the age of the trees from which the wood material is sourced. In the absence of any disclosure to the contrary, a skilled person would assume that wood for making the board product described by Suzuki et al would be sourced in accordance with common knowledge at the time relating to the age of wood used to make similar products. Existing methods of producing strand board in North America use native forest trees such as aspen, lodgepole pine, and yellow pine, as discussed by Suzuki et al, and generally these trees are *25 to 40 years old* when harvested.

Prior to the present invention, only the pulp and paper industries used trees with ages in the claimed range of 8-12 years. With specific regard to eucalyptus trees, these are typically allowed to grow to 15-25 years, or more, when used in plywood or solid lumber, and due to the inherent internal stresses of young trees, lumber made from young trees tends to split when dried.

It is respectfully submitted that the skilled artisan considering Suzuki et al would not have concluded that it would be obvious to form the strands "from plantation trees having an age between 8 years and 12 years," as this would have been contrary to common knowledge and practice at the time of the Suzuki et al invention, with regard to the age of

trees used to form wood products.

In the rejection of claim 13, it has been asserted that the claims are interpreted as "being directed to a board and not trees of a certain age" and that Applicants have not submitted "any evidence or analysis explaining how the properties of the boards differ from strands of different age trees." Applicants submit, however, that such evidence is not necessary as a skilled person would understand that boards manufactured from older trees would be different.

In any event, Applicants now submit further evidence in this regard in order to advance prosecution.

Attached hereto as "Attachment A" is a report entitled "Eucalypt Plantations for Solid Wood Products in Australia - A Review." This document particularly provides detailed data regarding the usage of eucalypt plantation trees and the properties of the wood from trees of different ages.

In the Executive Summary, at page iv, it is noted that growing plantation trees suitable for solid wood products takes 20 to 35 years depending on the characteristics of the trees and the site. It is also concluded on page v that the vast majority of the current hardwood plantation estate will not produce logs suitable for uses other than pulp and paper.

In contrast, the claimed product delivers performance comparable to that of solid wood products using wood from trees aged 8-12 years.

The typical usage of trees of different ages is discussed on page 14 and page 17 of the report. It will also be appreciated that unpruned trees can be used to make high quality strand products where typically trees need to be intensively pruned and thinned in order to yield quality wood.

Page 71 of the report discusses how the wood quality and age of the tree is related by way of the description of the growth process for trees. The following extract is particularly relevant:

> A tree grows by depositing a new layer of wood, under the bark, on the outside of the previous year's deposited wood (Figure 7.61). The wood that is deposited in a year's growth is different from the wood deposited in the previous year's growth, up until the tree reaches 20 to 40 years old, after which time the deposited wood is relatively consistent year-to-year (Figure 7.62).

In light of this, it will be appreciated that wood formed in the early years of a tree's growth is of low quality, and the large proportion of unacceptable low quality wood in young trees means that young trees could not be used to make high performance products. However, the claimed product has overcome this problem by dispersing the low quality wood throughout the strand matrix, and subsequently high performance products can be obtained with wood regarded as having low quality.

It is therefore submitted that the skilled person would appreciate that, at the time of the invention, there was a common understanding that eucalypt plantation wood from trees aged between 8 years and 12 years is not acceptable for making quality wood products. Rather, trees of this age were solely used in the pulp and paper industries. Such restrictions in the use of young trees were also well known at the time for other wood varieties.

In light of the common knowledge at the time, it is respectfully submitted that it would not have been obvious to the skilled person to use wood from eucalypt "plantation trees having an age between 8 years and 12 years" as recited in claim 13. There is no teaching in Suzuki et al to suggest that the use of young trees should be considered, and the common knowledge at the time would have effectively meant that the skilled person would expect inferior properties as a result of using young wood regarded as having low quality. Accordingly,

claim 13 is novel and non-obvious over Suzuki et al.

New independent claim 15 also recites the use of "strands of one or more 8 to 12 year old eucalypts," and new claim 17 depends from claim 16, and recites that the method of manufacturing the strand product includes "harvesting the logs from plantation trees having an age between 8 years and 12 years."

New independent claim 18 is directed to a method of manufacturing a hard wood strand product including a first step of "harvesting logs from plantation trees having an age between 8 years and 12 years."

Withdrawal of these rejections is requested.

Claim 3 has been rejected under 35 USC 103(a) over Suzuki et al in view of Shaner et al and Liu, and claims 4-6 and 8 have been rejected under 35 USC 103(a) over Suzuki et al in view of Shaner et al, with Shaner et al being cited for a disclosure of binder with resin and wax, and strands of a particular length, and Liu being cited for a disclosure of a binder of a methane di-isocyanate resin and wax.

Shaner et al and Liu do not, however, cure the defects of Suzuki et al as discussed above, and withdrawal of these rejections is requested.

In view of the foregoing amendments and remarks, Applicants submit that the present application is now in condition for allowance. An early allowance of the application with amended claims is earnestly solicited.

Respectfully submitted,

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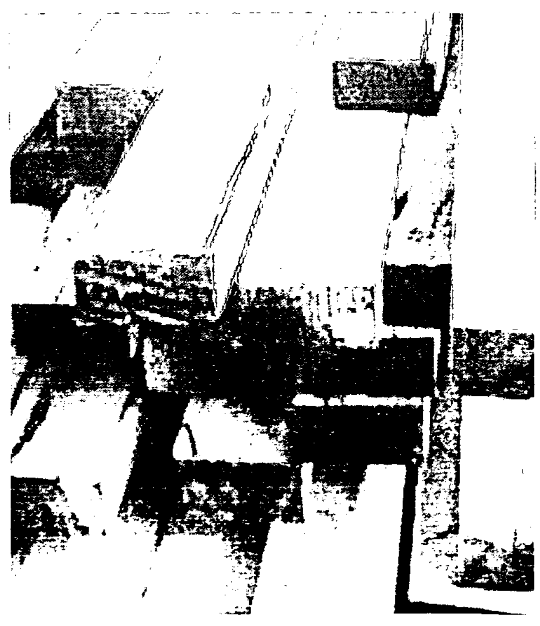
ATTACHMENT A

Australian Government

Forest and Wood Products Research and Development Corporation

Eucalypt Plantations for Solid Wood Products in Australia - A Review

'If you don't prune it, we can't use it'



Resource Characterisation & Improvement

Project No. PN04.3002

Eucalypt Plantations for Solid Wood Products in Australia – A Review
'If you don't prune it, we can't use it'

Prepared for the

**Forest & Wood Products
Research & Development Corporation**

by

G. Nolan, B. Greaves, R. Washusen, M. Parsons & S. Jennings

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Australian Government
Forest and Wood Products
Research and Development
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Contents

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Abbreviations

CCA	Copper Chrome Arsenic
dbh	Diameter at breast height of 1.3 m, either under-bark (UB) or over-bark (OB)
FSP	Fibre Saturation Point
ha	Hectare
IRR	Internal Rate of Return
LVL	Laminated Veneer Lumber
MAI	Mean Annual increment
MC	Moisture Content
MFA	Microfibril Angle in the cell-wall
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
NPV	Net Present Value
OD	Oven Dried at 103°C
SED	Small End Diameter (of log)
sph	Stems per hectare

Executive Summary

This review explores influences and impediments that impact a solid products industry's ability to profitably process a plantation hardwood resource over time. That is, operating as a sustainable industry. For this study, solid wood products include natural rounds, sawn timber and veneer products but exclude products reconstituted from wood chips or fibre.

Significant eucalypt plantations exist around the world and some are being milled for solid wood products. However, Australia does not currently have a solid wood products industry that profitably processes plantation eucalypts. Australia's hardwood product industry is a mature industry that depends on harvesting native forest for its resource. It generates considerable regional economic activity and employment, producing about $1 billion of sawn timber in 2003-04, and generating at least as much again in further processing and other products. About 32,500 people are directly employed nationally in hardwood forest management, harvesting, sawmilling and timber processing.

However, the industry has been in transition for at least fifteen years driven by reduction in harvests from native forest and competition from lower priced plantation softwood products. In response, the hardwood industry has moved from producing low value unseasoned products to higher value, seasoned appearance and niche structural items. Eucalypts have performance characteristics in these areas that most softwoods cannot match. As such, they are not true commodity products but differentiated ones that can sustain a higher price.

Products, markets and processing

Hardwood consumption has steadily declined since the 1960s to about 1.1 million m^3 in 2003. Softwood consumption has increased to about 3.5 million m^3 and it now dominates the structural timber market. The proportion of hardwood used in appearance application has increased progressively with demand that is underpinned by its natural visual appeal.

Eucalypt hardwood plantations do not bring a new or different solid wood product to the market. They will supplement the supply of hardwood logs from native forests. So the opportunities and constraints that apply to current solid hardwood products are likely to continue for those milled from a plantation resource. The major products groups are:

- **Natural rounds:** debarked and often preservative treated logs used as piles, posts, poles, landscape elements and beams. Natural rounds provide a substantial potential market for plantation eucalypt thinnings. Studies have found that they are fit for purpose and industry has begun to introduce them into the market.
- **Sawn hardwood:** boards used as an appearance, structural, or industrial product in building, furniture or general construction. This is the major market area of solid hardwood products and studies have found that a suitably grown plantation resource can provide a useful feedstock for each product area. While there are differences between species and the age of the plantation, knots and other defects associated with branches are the major causes for down grade of products for both appearance and structural applications. Early pruned logs appear to provide substantially improved recoveries and product quality in all species.
- **Veneer:** thin slices of material used for appearance and structural applications. This could be a major market area except for price competition with softwood and imported products. Studies have found that a suitably grown plantation resource can provide a useful feedstock for veneer, plywood and laminated veneer lumber (LVL) production but knots and other defects can lead to significant down grade.

Technological advances can influence the productivity and profitability of growing and processing eucalypt hardwoods by potentially increasing recovery of usable product and reducing the unit cost of production. However, technological advances are unlikely to negate the two most important market drivers for solid hardwood products: the dominant

demand for wood without significant natural feature, such as knots and gum vein; and the cost competitiveness of exotic softwood products in the commodity structural market.

Log availability

Australia had 676,000 ha of hardwood plantations in 2003 with an estimated 107,000 ha, or about 17.4%, managed specifically for sawlog production. A significant proportion of these sawlog plantations is owned by or established in cooperation with state agencies. These plantations are also young, with 62% planted since 1995 with expected rotation length of 20-35 years.

Some have proposed that plantations can soon replace log supply from native forests. Others hope hardwood plantations will increase log supply to a growing regional industry. However, under current policies, the estimated sustainable hardwood log availability from Australia's public forest is expected to fall by 36% or 776,000 m^3 between 2001 and 2039 and by 25% or 115,000 m^3 from private forests. If policies change and more native forests are reserved, these falls could be more extreme. By 2035, log availability from hardwood plantation is estimated to reach only about 376,000 m^3. So, by 2035, plantation logs are likely to make up:

- less than 15% of the 2001 native forest supply level
- only about 18% of total estimated log availability in 2035
- less than half of the estimated log availability lost from public native forest between 2000 and 2035.

It is unlikely that existing plantations being managed for fibre production will:

- yield significant sawlog suitable for most profitable solid wood products
- respond to late silvicultural treatment (after about age 4) in a way that improves log quality for solid wood products significantly.

Silviculture

Logs suitable for solid wood products probably have the longest growth cycle of any renewable resource. Growing a suitable resource for solid wood products involves:

- selecting species that have growth and wood quality characteristics suited to producing solid wood products on relatively short rotation times
- planting selected trees on high quality sites at a relatively high initial stocking
- pruning the trees several times from an early age (about age 2 to 3) to reduce the size of the knotty core and encourage the growth of clear wood
- thinning the number of trees on the site severely before canopy closure to about 150-250 stems per hectare
- grow the trees to a suitable market diameter. This takes 20 to 35 years depending on the characteristics of the trees and the site.

This process provides the widest possible opportunity for marketing the logs as it focuses on producing a resource for:

- appearance grade recovery for the sawn timber, with a fall-down market of structural and industrial timber
- appearance and high quality structural veneer, with fall down into internal laminates, and strand material.

Economics

To be sustainable, producing solid wood products must be economically viable for each sector of the industry: the solid wood producer; the plantation grower; and as only some part of any tree or plantation will be suitable for solid wood products, producers of complementary wood products. Solid wood producers generally make their highest

returns from appearance material with little natural feature. Returns from high feature structural products are limited by competing commodity products, especially softwood. Studies on mill profitability are rare but producers have indicated that if the recovery of appearance and low feature material from the available resource falls below a threshold level, the feasibility of processing the material at all is in doubt.

Profitability models for growing plantation hardwoods are more developed. They show that growing a plantation for high value sawlogs can provide suitable long term returns. However, these projections are sensitive to log price, site productivity, rotation length and land costs. Generally, a mean annual increment at age 10 of at least 20 to 25 m^3/ha is required for operations to be profitable.

Conclusions

Eucalypt plantations have been established to provide industry with a supplementary source of wood fibre. Significant development work has been done into species selection and silviculture, particularly when growing for fibre. With continuing restrictions on access to native forests, in past decades government programs have sought to encourage or establish hardwood plantations specifically for solid wood products. This review assessed the current status of Australia's plantations, their suitability for solid wood product and industry's capacity to use them. It found that:

- The vast majority of the current hardwood plantation estate will not produce logs suitable for a profitable solid wood products industry.
- It is highly likely that a solid wood products industry can profitably process and sell material from a future plantation hardwood resource if that resource includes a high proportion of high quality logs with significant clear wood.
- This industry's production strategy will likely focus on supplying a high quality and high value appearance hardwood market. Structural and other products will likely supply niche markets only.
- The general parameters of growing and processing suitable logs are known but there is considerable uncertainty in the sensitivities of the boundaries of practice.
- Unless more plantations managed for hardwood sawlogs are established in the near future, Australia will have to meet its demand for high quality hardwood appearance timber for building and furniture with increased imports.

Recommendations

For the solid wood products industry, the major issues to be addressed in moving to a plantation hardwood resource are log availability and improved production optimisation techniques. The primary areas that require research are:

- determining the growing cost and value of logs grown specifically for high value solid wood products
- improved understanding of market structures, the impact of particular wood characteristics on product value and related economic aspects
- improved log availability modelling from the plantation and native forest estate
- increasing value from the current hardwood plantation resource by optimising processing to minimise degrade, especially during drying
- exploring the mechanisms and control of growth stress and tension wood effects
- refining understanding of the interactions of site, species and silviculture
- improvement of log output and quality through tree breeding.

Work in these areas should be deliberate comparative studies, operating across species to a standard methodology that integrates growing and milling results, and provides improved assessment data for plantation inventory and economic modelling.

1.0. Introduction

1.1. Aims

This review explores influences and impediments that impact a solid products industry's ability to profitably process a plantation hardwood resource. Profitably is taken to mean profitable over time, and therefore a sustainable industry. It reports on research covering:

- The solid wood products that can be made from plantation hardwoods
- The economic or commercial viability of producing these products from the available and potential resource
- The likely wood properties of this resource
- The relationship between silvicultural and genetic aspects of plantation hardwood forestry, and wood properties and product recovery.

While information on regrowth hardwood is included, this report focuses on growing and processing the eucalypt or closely related native hardwood species, such as *Corymbia spp.,* that make up most of Australia's hardwood plantations. Unless the context indicates otherwise, the terms *hardwood* and *eucalypt* are used in the text to refer to this group of species.

1.2. Definitions

This study uses the Federal Department of Agriculture Fisheries and Forestry's definition of:

- **a plantation** as *an intensively managed stand of trees of either native or exotic species, created by the regular placement of seedlings or seed*
- **regrowth** as *native forest containing a substantial proportion of trees in a younger growth phase, actively growing in height and diameter. Regrowth forests may contain scattered individuals or small occurrences of ecologically mature or old-growth trees*
- **native forest** as *any locally indigenous forest community containing the full complement of native species and habitats normally associated with that community, or having the potential to develop these characteristics.*

For the purposes of this study, solid wood products include:

- **Natural rounds -** debarked logs cut to length
- **Sawn timber -** appearance and structural material and products assembled from them, such as glue laminated elements
- **Veneer -** appearance and structural material, and wood panels made of veneers, such as plywood and LVL.

This definition excludes products reconstituted from logs chipped into pieces or converted to fibre, or fuel wood.

A large number of species are mentioned in this report and generally, these are referred to by their botanical name only. Appendix 1 includes a list of the botanical name, common name and a general description of species mentioned.

1.3. Review process

Research can be viewed as two general types:

- Formal research: investigation conducted in a systematic manner by trained researchers and reported in some written form

- Research-in-action: this includes:
    - The understandings that industry members and researchers develop during their day-to-day activities
    - Research conducted in an informal, 'trial and error' or evolutionary way.

  The results of research-in-action are often not formally reported. They become part of the researcher's or company's skill or experience base.

The hardwood solid products industry is a traditional, long-established industry with relatively low capital and technological barriers to new entrants. As such, research-in-action is quite common.

This review has incorporated the results of both research types collected by:

- a broad literature search
- discussions with key industry members and researchers. A list of practitioners interviewed in detail is included in Appendix Table 1.1.

In this document, information from published papers has generally been referenced, while information provided by industry members has not.

1.4. The knowledge base on eucalypt plantations

While Australia is the home of most of the world's eucalypt species, extensive eucalypt plantations exist in countries throughout South America, Southern Africa, Asia and the Iberian Peninsula. While most are managed to produce fibre, they also produce some resource for solid wood products.

Internationally, research and development organisations have been actively investigating aspects of growing and processing plantation eucalypts for solid wood products. These organisations include INFOR in Chile, LATU in Uruguay, INTA in Argentina and EMBRAPA in Brazil, CSIR and the University of Stellenbosh in South Africa, CIRAD Foret in France, CIS-Madera in Spain and Forest Research in New Zealand. Similarly, major companies, such as Forest Tapebicoa in South America, have been developing expertise in both growing and milling eucalypts into solid wood products.

With its access to slowly grown eucalypt hardwoods from native forests, Australia did not begin establishing significant areas of eucalypt plantations for solid wood products before the 1990s. Until then the bulk of Australian research focused on growing eucalypts in plantations for fibre. Research into processing plantation hardwood for solid wood products increased only recently.

Sustainably producing solid hardwood products from a plantation eucalypt resource includes growing and harvesting trees, grading and processing the logs into products and then profitably selling these products into a marketplace. These areas are not equally covered in Australian or international research literature. Published research results tend to focus on:

- broad statistical characterisation of market demand
- the current plantation estate and its distribution
- recovery from milling some sections of the plantation estate
- the wood properties of some species
- silviculture.

Of these, the overwhelming majority of published research results deal with silviculture. The areas noticeably underrepresented are:

- linkages between the activity areas, such as growing for a target product
- drying the timber, especially collapse prone material

- characterisation of the market for hardwood products
- production cost for or recoveries of hardwood products
- the combined economics of growing and processing.

To cover these areas at least in part, supplementary research was conducted as part of this review. It was considered that it would be better to prepare and include preliminary results and place them in the public domain for comment rather than make no comment.

In addition to the imbalance in coverage of particular areas, the results of some research and research-in-action do not distinguish adequately between technical feasibility and commercial viability. That is, whether something is physically possible, profitable or both. Some research concludes that something can't be done, when it is technically possible but not commercially viable. Other research concludes or implies that if something is technically feasible, it must also be commercially viable. Neither proposition is necessarily correct. In reality, technical feasibility and commercial viability are both transient influences as technology and market factors are constantly changing.

Throughout this report, attempts have been made to reflect technical and commercial considerations as clearly and evenly as possible.

2.0. The current industry position

Unlike countries such as Brazil, Chile and Spain, Australia does not currently have a solid wood products industry that is profitably processing plantation eucalypts. If one is to evolve, it is likely to do so from the existing solid hardwood production and plantation hardwood growing industries. The profile of Australia's plantation hardwood growing industry is reported in Section 3.

2.1. The existing hardwood solid product industry

Australia's hardwood solid product industry is a mature industry that has existed since European colonisation. It largely relies on milling native forest resources; processing 3.03 million m^3 of eucalypt logs into 1.063 million m^3 of timber in 2002-03 (ABARE 2004). Its solid products output includes natural rounds, sawn appearance and structural hardwood, decorative veneer and a small quantity of structural veneer used for plywood. Domestic and commercial building and furniture construction accounts for around 90% of all sawn timber used in Australia (BIS Shrapnel 1998).

The industry is diverse. Companies vary considerable in size and sophistication and process a large number of species with often significantly different physical properties. These factors generate particular and often highly regional market opportunities and approaches. The industry generates considerable regional employment, especially in Tasmania, Victoria, the north coast of NSW, parts of Queensland and the south west corner of West Australia. It produces about $1 billion of sawn timber in 2003-04, and generating at least as much again in further processing and other products (ABARE 2004). About 32,500 people are directly employed nationally in hardwood forest management, harvesting, sawmilling and timber processing (FAFPESC 2005)

The industry has been in transition for at least the last fifteen years driven by:

- reduction in harvests from native forest
- competition from increasingly available solid timber cut from exotic plantation softwood.

Reduction of harvests from native forests

The area of Australia's native forests available for timber production has decreased over recent decades while reserves have increased. Also, the productivity of the available native forest may have been affected by past practice and natural events. For example, the areas of native forest in natural conservation reserves increased by 1.7 million hectares until the end of 2002 to 6.6 million hectares (Bureau of Rural Science 2003). At the same time, estimates of sustainable log yields from the remaining forest estate have declined (Nolan 2002). The affects of this on the hardwood production industry have been considerable. It has:

- reduced the volume and quality of log supplies for milling.
  As shown in Figure 2.1, the volume of logs available for processing has reduced from 5.79 million m^3 of non conifer timber (FAO) in 1980, to 3.03 million m^3 in 2003 (ABARE 2004). To minimise this reduction and its effects, native forests have been subject to greater silvicultural intervention and trees are being harvested on average at a younger age and a smaller size. As such, log quality has declined.
- increased pressure to add value to the harvested resource.
  This has been to improve the economic and social return from native forest logging and, as discussed below, to ensure the industry's continued commercial viability.

The reduction in log supply and drive for greater value adding has led to several broad industry effects:

- The number of hardwood mills has reduced significantly and production has been concentrated in fewer, larger operations.
- The size of board and general grade recovery from logs has decreased.
- The percentage of material dried before sale has increased significantly and with it, attendant production problems such as internal checking.

Notwithstanding efforts to improve value adding, the industry's capacity to optimise production is limited by a resource that varies considerably by species, region and growing conditions and a regional expertise base.

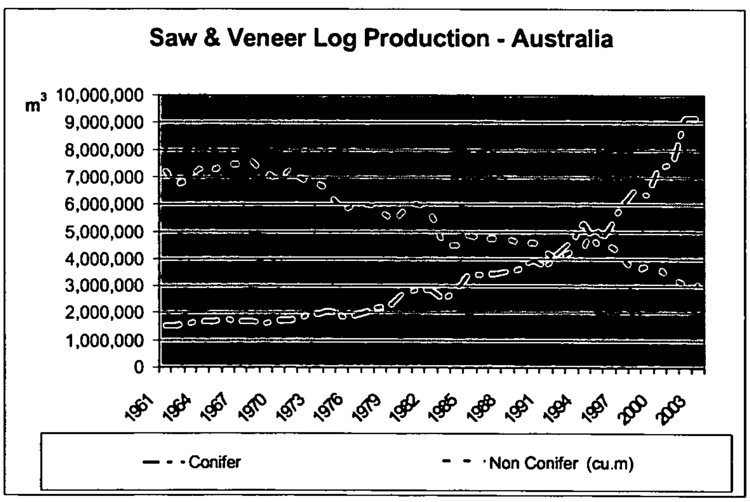


Figure 2.1. Australia's saw and veneer log production (FAO 2004)

Competition from softwood

Production of sawn exotic plantation softwood products has increased in Australia considerably since the late 1970s. Plantation softwood is easy to use, suitable for a broad range of structural applications, easier to process and about half the price in the market of similar hardwood products. As hardwood producers cannot match these prices, sawn

and engineered softwood products have displaced sawn hardwood in many structural applications. They now dominate these markets. As shown in Figure 2.2, softwood now provides about 73% of Australian sawn timber production (FAO). It almost certainly makes up a larger proportion of the structural timber market.

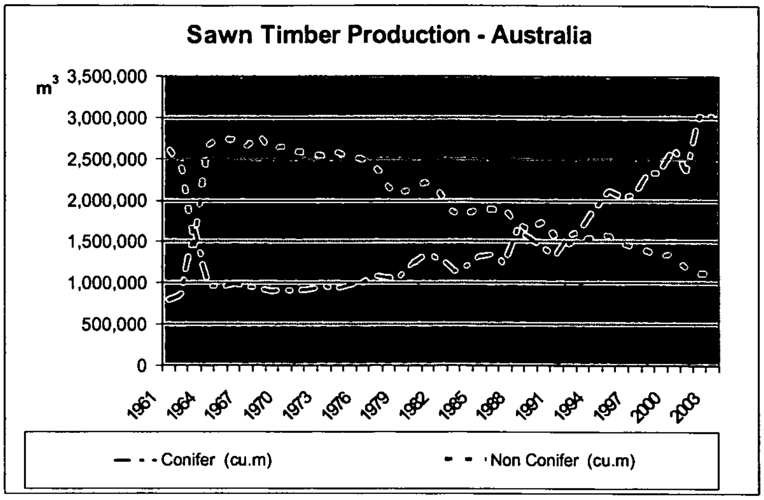


Figure 2.2. Australia's sawn timber production (FAO 2004)

2.2. Current industry production strategy

Historically, the Australian hardwood production industry milled predominantly unseasoned hardwood in small, low cost facilities and sold it into local markets. During the last 20 years, reducing log supply and competitive pressure from softwood has driven the industry from this position.

Statistics that separate production of solid hardwood into natural rounds, sawn appearance and structural timber, decorative veneer and plywood are not available. However, the largest hardwood millers in south eastern Australia all appear to be pursuing strategies that focus on supplying an integrated range of high value appearance products, such as flooring, lining and furniture stock, supported by niche structural products. Anecdotally, the largest companies have between 60-70% of their production in appearance product, 20-30% in structural and 10% in industrial timber. The structural and industrial wood is often product cut from the log that will not satisfy an appearance market. About 30% of hardwood produced by Tasmania's major millers is used in a single product area. That is strip flooring. While producers in northern NSW and Queensland have been partially protected from this trend by the durability and character of their species, they are also being forced to focus more on appearance markets.

The reasons for this are straightforward. Most hardwood products are significantly more expensive to produce and market than comparable softwood products. So the price differential between them is significant. However, eucalypt hardwoods have performance characteristics as appearance products that softwood cannot match. They are harder than plantation softwoods, with more regular grain and texture and an attractive range of colours. Also, most species are much more durable. Consequently, the hardwood industry has moved from producing lower value unseasoned, structural products to higher value, seasoned appearance and specialist structural ones. These are not true commodity products but differentiated ones that can sustain a higher price.

3.0. Products and markets

Society uses a wide range of forest products in seven major groups:

- natural rounds
- sawn timber
- veneer and wood panels made of veneers
- panels of reconstituted wood
- papers and cardboards
- fuel wood
- other products such as carbon, rayon, essential oils and foods.

While this report concentrates on the production and use of the first three groups, only some part of any tree or stand will be used in them. The remainder needs a market in product areas that are outside the scope of this report. If suitable product options are not available for the total rotation output, the economic viability of growing a plantation hardwood crop for solid wood products may be in question.

3.1. Solid hardwood products

Eucalypt hardwood plantations do not provide a new or different solid wood product to the market. They provide the hardwood production industry with an alternative to native forest for hardwood logs. Given this, the opportunities and constraints that apply to current solid hardwood products in the market are likely to continue for those milled from a plantation resource. These are detailed below.

3.1.1. Natural rounds

Natural rounds are debarked logs that are naturally durable or treated to be suitably durable, and are strong, long and straight enough for the required purpose. Generally, small diameter rounds with lengths up to 3.6 m are used in piles and posts, landscaping, and agriculture. Longer, larger diameter rounds find uses as utility poles, bridging and engineering timbers. The market for natural rounds is determined by strength, diameter, durability and price.

3.1.2. Sawn timber

Sawn hardwood is boards cut to a predetermined size from a log by a saw. Processed and graded appropriately, it is suitable for the full range of design and construction applications, such as:

- appearance products in building, furniture, or other artefacts
- structural products in building, general construction or industry
- general industrials product, such as pallet and case material and fencing.

Each of these product groups has differing performance requirements and values.

Appearance products

Hardwood timber is used in appearance applications when its visual appearance is acceptable or desirable and it has suitable strength, stability and integrity. The major market sectors for appearance hardwood products are:

- **flooring,** as conventional strip and overlay tongue and groove flooring, and parquetry

- **furniture and joinery**, as solid timber items or elements that combine solid timber and veneered board
- **lining and trims**, such as panelling, reveals and architraves
- **other fittings**, such as windows, doors and stairs
- **architectural structures**, such as exposed rafters, joists and frames.

The importance of each of these sectors varies considerably with the company, region and species. Regional or industry-wide figures are not available.

AS 2796-1999: Timber - Hardwood - Sawn and milled products is the applicable standard for appearance hardwood products and it defines three major product grades: *Select, Medium feature / Standard*, and *High feature*. The grades are separated by the amount of feature, such as gum vein, knots and checking, found in each board. *Select* material has the least amount of feature; *Standard* material includes a greater amount, while *High feature* allows the most. As almost all appearance grade hardwood is used seasoned, it has to be dried to a suitable moisture content.

Market acceptance and value

The acceptance and value of hardwood appearance products varies with grade, dimension, colour and, to a lesser extent, strength.

Though the acceptance of each grade varies marginally between states, demand for *Select* grade material dominates Australia's hardwood appearance market. As shown in Table 3.1, this preference translates into a premium for *Select* timber over other grades.

Table 3.1. Relative prices of flooring milled from nominal 100 x 25 mm material

Grade	***Select***	***Standard***	***High feature***
Relative price/m^3*	119%	100%	61%

* Prices are unweighted averages of wholesale flooring prices across four different eucalypt hardwood species or species groups in October 2004.

The demand and value of boards also varies with width, thickness and length.

As shown in Table 3.2, wide boards, especially those over 125 mm, attract a premium over narrow boards. Table 3.3 shows that due to increased production costs and specific demand, thicker boards attract a premium over thinner ones.

Table 3.2. Relative prices for *Select* boards nominally 25 mm thick

Width (nom)	**75**	**100**	**125**	**150**
Relative price/m^3*	93%	100%	100%	117%

* Prices are unweighted averages of wholesale prices from three suppliers across three different eucalypt hardwood species or species groups in October 2004.

Table 3.3. Relative prices for *Select* boards nominally 100 mm wide.

Thickness (nom)	**25**	**38**	**50**
Relative price/m^3*	80%	100%	114%

* Prices are unweighted averages of wholesale prices from two suppliers across two different eucalypt hardwood species or species groups in October 2004.

Longer boards generally attract a premium over shorter boards. Several companies overcome the problems of shorts by selling random length packs with an implicit or explicit guarantee on average length. Others have developed overseas market for shorts

where they are used as furniture blanks or a feedstock for parquetry and other products. Others discount shorts significantly.

Colour is a critical aspect of visual appeal. In national and regional markets, recognition and preference is generally for particular species, based on established perceptions of colour and suitability. This generates local premiums for particular species that are too complex to report here. For key applications, such as furniture and flooring, timber's mechanical properties are critical to its use. This creates particular market niches for species with acceptable characteristics and colours, again too complex to report here.

Several NSW companies are including plantation material in their strip flooring and parquetry lines but they do not currently identify it separately.

Structural products

Sawn hardwood is used in structural applications when it has suitable strength, stability, integrity, durability and economy for the task. Sawn structural hardwood products are generally used as:

- dry framing and formwork timber in domestic or other buildings
- large unseasoned sawn sections used in major engineering structures, such as wharf and bridge beams and decks, and as railway sleepers.

For short-term uses or interior applications such as framing, the major market determinant is price, followed by strength, stability and straightness. In long term external applications, the major market determinants are durability, price, strength and availability, with the importance of each dependant on the specific application.

Market acceptance and value

Green and dry timber framing was historically a major market for sawn hardwood. However, with the introduction of large quantities of softwood framing during the 1980s and 90s, and increasing competition for a dwindling log supply, much of that market disappeared (Gooding 1997). This was predominantly driven by price. As shown in Table 3.4. and Figure 3.1, the price of nominal 100 x 38 softwood studs is considerably lower than a similar hardwood stud performing the same task.

Table 3.4. Relative prices for nominal 90 x 35 mm dry timber

Species and grade	*Select* hardwood	Structural hardwood (F27, F17)	Softwood (MGP 10)
Relative price /m³*	175%	100%	48%

* Prices are unweighted averages of wholesale prices across three suppliers in three eastern states in October 2004.

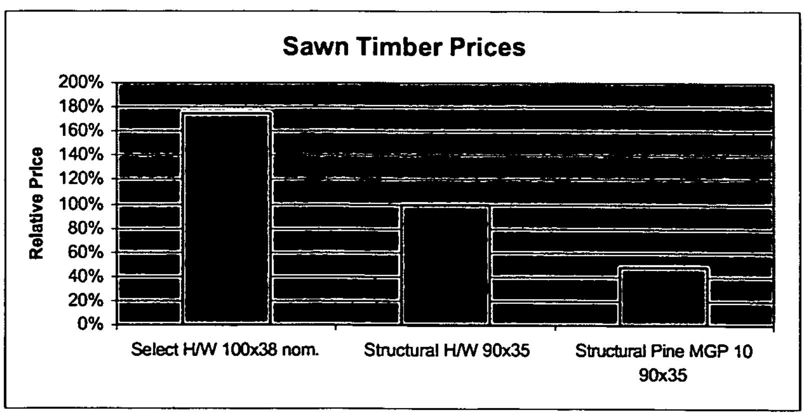


Figure 3.1. Relative prices for nominal 100x38 dry timber

While hardwood is generally stronger than softwood for the same size piece, this usually does not counteract the price difference. It appears hardwoods' extra strength only warrants the price premium in strength critical applications, such as in some truss members and laminated products.

High durability hardwood species can be used externally without treatment. While softwood can be chemically treated to increases its durability, there is resistance to using treated timber in some sectors. As a result, durable hardwoods have retained markets in decks, decking and other applications exposed to the weather or to termites.

Large unseasoned sections are often cut from logs of species that are strong, durable and not favoured for more valuable appearance products. Species used nationally for these types of application are various ironbarks, turpentine *Syncarpia glomulifera*, tallowwood *E. microcorys*, jarrah *E. marginata,* southern blue gum *E. globulus*, and silvertop ash *E. sieberi*. Anecdotally demand for these products is decreasing nationally, in part as a response to continuing supply constraints, especially of high durability material.

Industrial products

Sawn industrial products are pallet, case and paling timber. These are generally produced as either a by-product from the manufacture of appearance and structural products, or milled from low-grade logs. They are often sold unseasoned. Industrial material is usually a low cost product from low cost operations. Prices received per cubic metre are about half that of dry structural hardwood.

3.1.3. Veneer and veneer wood panels

Veneer is a thin layer or sheet of wood, cut from a flitch or log. Its thickness is set to match the end use, either appearance or decorative veneer and structural veneer.

Appearance veneer

Hardwood veneer is used in appearance and decorative applications when its visual appearance is acceptable or desirable and it has suitable physical characteristics for the task. The major market sectors for appearance veneers are furniture, joinery and lining. The veneer is often laid onto a wood panel, such as medium density fibreboard. The acceptance and value of decorative veneer varies with its appearance. Evenly coloured material is preferred over material with noticeable colour variegation. As is shown in Table 3.5, the presence of any natural feature reduces its value considerably.

Table 3.5. Relative prices for different veneer groups

Grade	Characteristic	Relative price /m^2
Face	Clear with very infrequent feature	225%
Natural	Some feature and infrequent gum	100%
Backing	Apparent feature	59%

* Relative costs are based on wholesale prices from one producer in October 2004.

Structural veneer

Hardwood veneer can be used in structural applications when it is incorporated into an engineered wood panel, such as plywood or laminated veneer lumber (LVL), and has the suitable strength, stability, durability and economy for the task. Structural hardwood veneer is almost exclusively peeled. Only one Australian mill currently peels structural eucalypt veneer. It makes about 8% of the nation's plywood (McNaught 2004, pers. comm.). Native forest logs are also exported from Tasmania to mills overseas and peeled for high impact-resistant plywood.

Like sawn structural hardwood, Australian produced engineered eucalypt hardwood panels are at a general price disadvantage to engineered softwood panels. They are only

used in applications where hardwoods' extra strength and wear resistance justifies the price premium. These include concrete formwork and high impact industrial flooring. Locally produced hardwood panels are also at a considerable price disadvantage to imported hardwood panels, mainly from South East Asia. Hardwood bracing plywood is being landed in Australia currently at about $450/m^{3,} a considerable discount on the $650/m^3 price for Australian produced softwood bracing plywood (McNaught 2004, pers. comm.).

Hardwood veneer can also be 'blended' with softwood veneers to make engineered panels that either have critical extra strength for only a modest cost penalty or achieve a traditionally accepted strength level with weaker or lower grade softwood veneer.

3.2. Demand for solid hardwood products

Australians consumed about 4.69 million m^3 of sawn timber and 0.41 million m^3 of plywood in 2003-04. Of the sawn timber about 1.10 million m^3 (23.5%) was hardwood, of which 143,200 m^3, 13% of consumed hardwood, was imported (ABARE 2004). The remainder of the sawn timber was softwood. Of the plywood, most locally produced plywood is made from softwood, while about 65% of the 173,000 m^3 of ply imported is tropical hardwoods, mainly from South East Asia. An estimated 41,500 m^3/year of hardwood logs are harvested to produce poles used for electricity transmission lines (Ximenes et al. in press). Figures are not available for the use of natural round hardwood poles in landscaping and similar applications.

As shown in Figure 3.2, Australia's total apparent consumption of sawn timber has remained relatively stable in the last 40 years. As the population has increased in that time, total apparent consumption per head has declined. This is in part due to changes in construction practices and substitution of solid timber products by more efficient engineered wood products, wood panels and other materials such as steel and concrete.

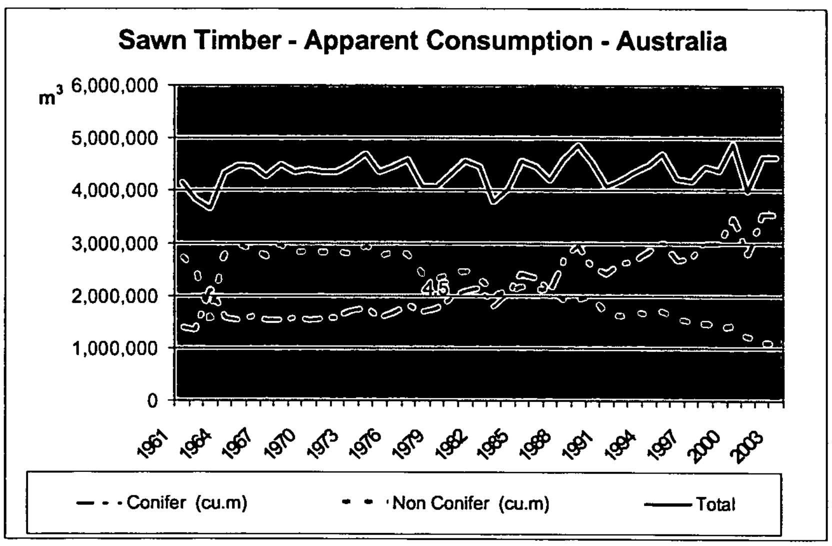


Figure 3.2. Australia's apparent sawn timber consumption (FAOSTAT 20040

About 80% of sawn timber is used in building (BIS Shrapnel 1998). Consequently, its consumption fluctuates in broad alignment with housing starts (ANU Forestry 2002a). However, the mix of sawn timber consumed has changed dramatically. Hardwood consumption has steadily declined from about 3 million m^3 in the 1960s to about 1.1 million m^3 in 2003, while softwood consumption has increased to about 3.5 million m^3.

Estimated consumption of timber in the residential sector, including detached houses, multi-unit dwellings and renovation/additions, compiled by building industry survey, is shown in Table 3.7. This shows that about 15% of Australian and 28% of imported

hardwood, mainly South East Asian tropical species, is used in appearance applications. About 48.3% of Australian hardwood is used in internal structural applications while 28.9% is used in external applications such as decking and fencing.

Table 3.6. Volumes of sawn timber used in Australia in 1999 by timber type and building application in the residential sector (BIS Shrapnel 2000)

	Australian HWD		Imported HWD		Radiata pine[2]		Other pine[3]		Total	
Appearance	Vol.	%	Vol.	%	Vol.	%	Vol.	%	Vol.	%
Floor boards	67.7	*8.5*	8.6	*2.9*	12.8	*0.7*	17.7	*5.1*	107	*3.2*
Skirting/Architraves	16.2	*2.0*	28.8	*9.6*	34.3	*1.8*	12.1	*3.5*	91.4	*2.7*
Facia	8.5	*1.1*	0.3	*0.1*	25	*1.3*	15.4	*4.4*	49.2	*1.5*
Windows	14.3	*1.8*	22.9	*7.7*	6.9	*0.4*	25.7	*7.4*	69.8	*2.1*
Doors	8.75	*1.1*	23.3	*7.8*	3.6	*0.2*	7.8	*2.2*	43.5	*1.3*
Structural										
Sub-flooring	201	*25.3*	1	*0.3*	41.7	*2.2*	47	*13.5*	291	*8.7*
Wall frames	56.5	*7.1*	3.9	*1.3*	633	*33.2*	43	*12.3*	736.5	*22*
Roof frames / trusses	102	*12.8*	0.97	*0.3*	554	*29.0*	53.6	*15.4*	710	*21.2*
Ceiling frames	24.2	*3.0*	6.9	*2.3*	323	*16.9*	21.1	*6.0*	375	*11.2*
Fencing	210	*26.4*	4.8	*1.6*	187	*9.8*	13.7	*3.9*	415	*12.4*
Decks[1]	13.2	*1.7*	17.5	*5.8*	17.7	*0.9*	21.2	*6.1*	69.6	*2.1*
Pergolas	6.2	*0.8*	0.19	*0.1*	17.7	*0.9*	12	*3.4*	36.1	*1.1*
Other	65.9	*8.3*	180	*60.2*	52.3	*2.7*	58.6	*16.8*	357	*10.7*
Total Appearance	115.45	*14.5*	83.9	*28.0*	82.6	*4.3*	78.7	*22.6*	360.9	*10.8*
Total Structural	613.1	*77.2*	35.26	*11.8*	1774.1	*92.9*	211.6	*60.6*	2633.2	*78.6*
Total Usage	794.45		299.16		1909		348.9		3351.1	
% of the market	*23.7*		*8.9*		*57*		*10.4*			

Notes

1. Decks include both the structure and the decking.
2. Includes radiata pine from New Zealand
3. mostly Douglas fir and Western red cedar

While projections indicate that softwood and softwood composites will continue to be substituted for hardwood in the structural market (BIS Shrapnel 1998), long term trends in consumer affluence and consumption may reinforce hardwood's markets in appearance products. There appears to be a correlation between increasing affluence and technical sophistication on one hand and anxiety over a consumer's environment on the other. This encourages a desire for freshness, natural materials and processes, and cocooned living patterns, especially in the home (Wilson 1993). While this trend probably works against native forestry, it appears to work in favour of timber, the only major building material that is natural. As this desire for the natural extends into domestic finishes and lining, it can support a market for appearance hardwood. Combined with hardwood's wear and cleaning characteristics, producers believe its natural appeal has certainly underpinned continuing demand for appearance hardwood flooring over the last five years.

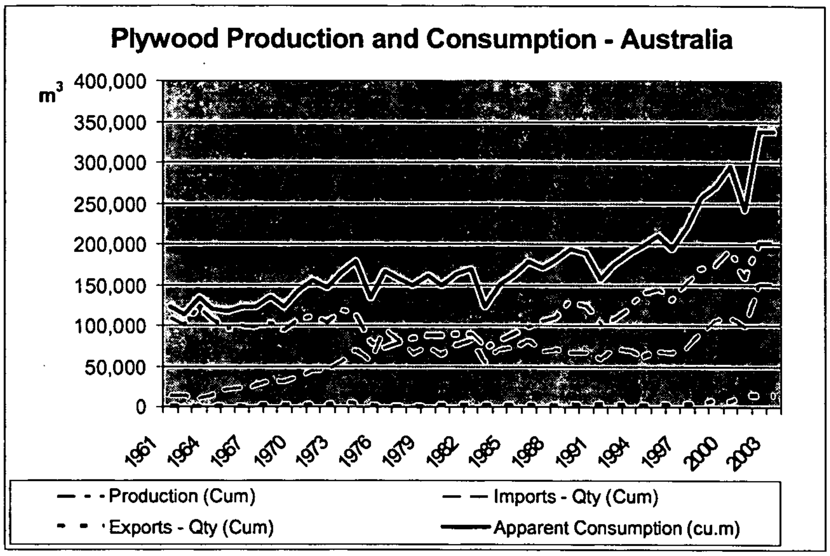


Figure 3.3. Australia's apparent plywood consumption (FAOSTAT 2004)

As shown in Figure 3.3, Australia's total consumption of plywood has increased sharply especially since the early 1990s. Total consumption per head is increasing. This is due in part to the increasing use of engineered 'plywood' products such as LVL and I-beams in the last decade.

Broad international demand for hardwood products is obviously an important factor in understanding the potential market for Australian produced solid wood products. However, assembling an assessment of this is beyond the scope of this report.

Future product demand

Greaves (2003) estimated future demand for solid products by adjusting current per capita consumption rates for probable future trends to 2030 and applying these rates to the projected domestic population of 24 million at that time. As shown in Table 3.6, this estimate assumes decreases in per capita use of sawn timber, newsprint and printing and writing paper, and increases in per capita use of panel products (substituting for structural solid wood). Production of native forest sawn timber was assumed to be reduced by 30%, as were pulpwood chips. Estimates of production in 2030 do not include production from plantations established after 1995.

Table 3.7. Apparent consumption and production of forest products: 2000 estimated actual (FAOSTAT 2003) and 2030 predicted (Greaves 2003)

wood product class	unit	2000 estimated actual				Australia 2030 predicted excluding 250,000 ha of plantation			
		consumption total	consumption per person	production total	shortfall: consumption production	consumption total	consumption per person	production total	shortfall: consumption - production
sawn timber	m3	3,997,000	0.21	3,525,000	472,000	3,997,000	0.17	3,041,571	955,429
panels - plywood/LVL	m3	215,000	0.01	157,000	58,000	797,500	0.03	157,000	640,500
panels - particle board/OSB	m3	908,000	0.05	904,000	4,000	1,672,868	0.07	904,000	768,868
panels - MDF	m3	413,000	0.02	712,000	-299,000	521,684	0.02	712,000	-190,316
veneer sheets	m3	13,000	0.00	5,000	8,000	16,421	0.00	5,000	11,421
paper - newsprint	tonne	691,000	0.04	465,000	226,000	872,842	0.03	465,000	407,842
paper - printing and writing	tonne	1,037,000	0.05	554,000	483,000	982,421	0.04	554,000	428,421
paper - wrapping and packaging	tonne	1,223,000	0.06	1,409,000	-186,000	1,544,842	0.06	1,409,000	135,842
paper - household and sanitary	tonne	246,000	0.01	204,000	42,000	310,737	0.01	204,000	106,737
wood fuel	m3	6,707,506	0.35	6,707,306	200	8,472,639	0.35	4,695,114	3,777,525
pulpwood chips domestic	m3	1,778,000	0.09	12,311,000	0	2,245,895	0.09	7,386,600	5,392,295
pulpwood chips export	m3	10,533,000	0.55			10,533,000	0.44		

3.3. Supply of solid hardwood products

Historic supply of Australian hardwood products is reported in Section 2.2. As shown in Figures 2.2 and 3.2, total domestic hardwood supply has declined broadly in line with demand. This has probably been driven by a combination of reduced supply of sawlog and increasing processing costs, and substitution by increasing volumes of cheaper softwood, wood panels and other material.

Anecdotally, the reduction in hardwood supply has lead to increased timber imports of specialist timber and substitution of timber with other materials. With the reduced supply of West Australian jarrah *E. marginata* in recent years, the use of imported dark or red South East Asian tropical species as a replacement appears to have increased in external decks in domestic and multi-residential applications. Currently, there seems to be little connection in the public domain between the increased reservation of native forests and decreased supply of specialist Australian produced timber. Also, over the last decade, the increased competition for logs has restricted supply of engineering timbers. As ready supply is fundamental to completing an engineering project successfully, engineers appear to be disregarding timber as a viable material option in this type of project.

Australian eucalypt sawlog availability estimates are included in Section 4.

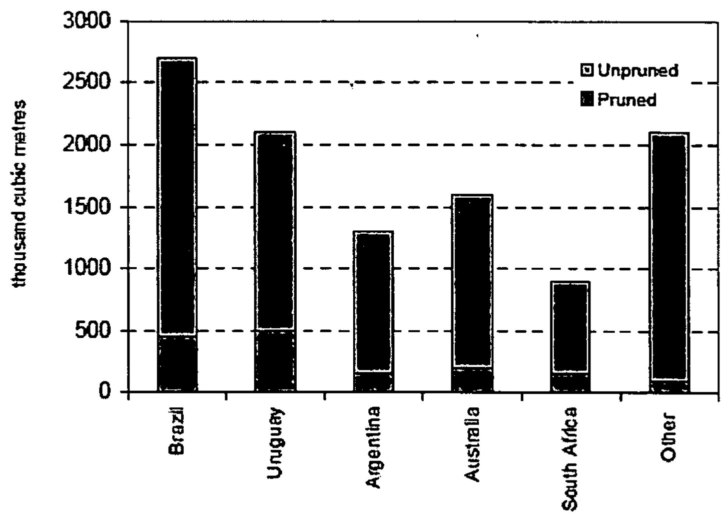


Figure 3.4. Eucalyptus sawlog supply forecast 2015 (URS 2004 reporting Donnelly et al. 2003)

Internationally, Australia is only one of many countries growing and milling eucalypts. There are an estimated 15-20 million hectares of industrial eucalypt plantations with about 46% being in South America and 25% in Asia. The global supply of eucalypt sawlogs from plantations is estimated to be around 3 million m^3 per annum at the current time (Donnelly 2003) and estimated to increase to 10.6 million m^3 per annum in 2015. The projected distribution of sawlog by country is shown in Figure 3.4.

Austin (2001) and other Australian practitioners report that major South American companies are operating green and dry sawmills, and plywood peeling and pressing operations as integrated businesses on one site, milling material originally grown for fibre. While much is used in structural applications, the resource is increasingly being grown and milled for high quality appearance products, such as flooring and docked small-sized components. Often with FSC environmental certification for their plantations, producers are exporting this material to North America and Europe, where there is no history of acceptance of eucalypt, and to Australia, where there is. Observers believe that South American producers are likely to be offering increasing quantities of this material to Australian and international markets in coming years.

4.0. Log availability

The availability of plantation logs for solid hardwood products is a function of the area of plantation under management, the silvicultural regimes employed in those plantations, their age, and their likely yield, given site conditions, species and other considerations.

4.1. Australia's plantation estate and its management

Australia has a significant plantation estate and a stated vision to establish a larger one. At the end of 2003, there were an estimated 1,665,693 ha of plantations in Australia of which an estimated 675,962 (41%) were hardwood plantations. The distribution of these plantations by state is shown in Table 4.1. About 60% of all hardwood plantations are one species, *E. globulus*. Government and industry policy is to develop the combined plantation estate to 3 million hectares by 2020 (Ministerial Council on Forestry 1997).

Table 4.1. Total area (hectares) of plantations by species group and state in 2003 (National Plantation Inventory [NPI] 2004)

State	Hardwood	Softwood	Unknown	Total
Australian Capital Territory	65	5,264	0	5,329
New South Wales	50,977	280,251	0	331,228
Northern Territory	4,448	3,817	0	8,265
Queensland	30,520	181,088	1,247	212,855
South Australia	37,119	120,493	261	157,872
Tasmania	146,641	76,104	0	222,745
Victoria	154,650	211,961	0	366,611
Western Australia	251,542	109,246	0	360,788
Total	**675,962**	**988,223**	**1,508**	**1,665,693**
	41%	**59%**		

Australia's hardwood plantations are managed under three broad silvicultural regimes:

- **unthinned and unpruned** - a stand of trees established with a high stocking rate subject to minimal silvicultural intervention after planting, and grown for about 10 years
- **thinned and unpruned** - a stand established and thinned one or more times and grown for 20-30 years. The affects of thinning on log output and quality varies with the species and retained stocking
- **thinned and pruned** - a stand established and thinned and pruned one or more times to a final stocking rate, and grown for 20-30 years

The first is nominally a pulpwood regime. The latter two are nominally sawlog regimes.

4.2. Plantations for sawlogs

As part of this review, a survey was conducted to determine the areas managed under the last two regimes in six National Plantation Inventory (NPI) regions: Gippsland, the Green Triangle in South Australia, north coast NSW, SE Qld, Tasmania and Western Australia. Jointly, these regions contain over 615, 000 ha, or 90% of Australia's hardwood plantations. From the survey responses, it was estimated that about 107,000

ha of the hardwood plantations within these regions, about 17.4%, are managed for sawlog production. That is, either thinned and unpruned or thinned and pruned. It is not currently possible to separate between these two regimes. Relative areas of hardwood plantations managed for sawlog are shown by state in Figure 4.1, while Table 4.2 and Figure 4.2 show the age profile of these plantations.

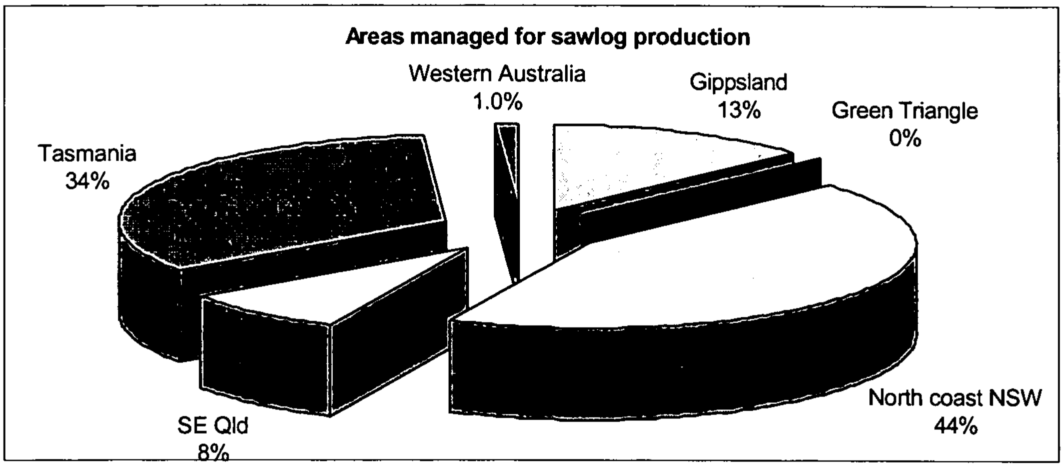


Figure 4.1. The proportion of sawlog managed hardwood plantations by NPI region

Table 4.2. Estimated area and ages of sawlog managed hardwood plantation in 2003 (hectares)[2]

Planting period	Gippsland	Green Triangle	North coast NSW	SE Qld	Tasmania	Western Australia	Total
Unknown	0	0	876	10	0	1,080[1]	1,966
pre 1970	1,375	0	4,197	920	3	0	6,495
1970-74	1,597	0	7,773	0	0	0	9,370
1975-79	1,855	0	3,375	11	42	0	5,283
1980-84	1,228	0	1,356	35	675	0	3,294
1985-89	1,806	0	669	14	2,651	0	5,140
1990-94	721	0	1,020	51	7,404	0	9,196
1995-99	574	0	15,822	2,225	10,829	0	29,450
2000-03	4,760	0	11,934	5,735	14,413	0	36,842
Total sawlog managed	**13,916**	**0**	**47,021**	**9,001**	**36,017**	**1,080**	**107,036**
Total Plantation	**27,806**	**115,336**	**48,663**	**30,933**	**141,018**	**251,542**	**615,298**
% sawlog managed	50.0%	0.0%	96.6%	29.1%	25.5%	0.4%	17.4%

Source:

1. Brennan et. al 2004.
2. National Plantation Inventory.

As shown in Table 4.2 and Figure 4.2, the distribution and age profile of sawlog managed plantations are highly concentrated. About 79% of plantations managed for sawlog are on the north coast of NSW or Tasmania, while 62% has been planted since 1995. The 47% of material planted in Tasmanian and Victoria is predominantly a mixture of Southern blue gum *E. globulus* and Shining gum *E. nitens*. The material in the north coast of NSW and SE Queensland is a combination of species including *E. pilularis, E. saligna, E. grandis, Corymbia* species, *E. dunnii and E. cloeziana*.

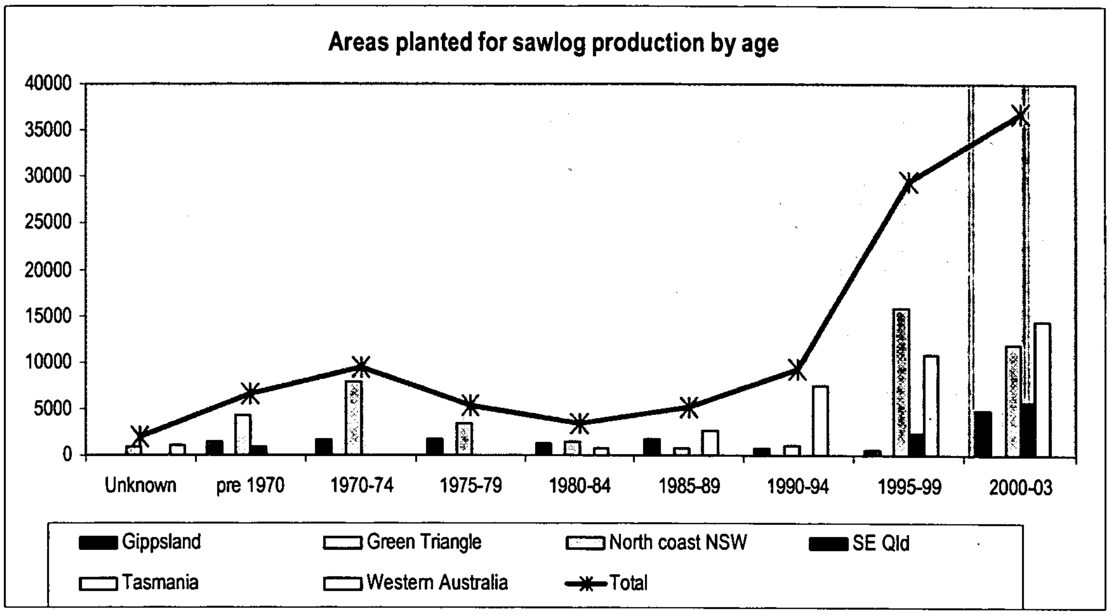


Figure 4.2. Hardwood plantations for sawlog production by age

A significant proportion of hardwood plantations managed for sawlog are owned by, or established in cooperation with, state agencies, particularly in Tasmania, NSW and Queensland. Some private plantation companies offer veneer and sawlog regimes as investment options but it appears that these account for less than 10% of their plantings.

Prospectus requirements and other legal constraints bind much of the remaining hardwood plantation resource to fibre production for at least the prospectus period. While it is probable that these arrangements could be varied and a different management regime adopted if sufficient economic drivers exist, it is technically unlikely that late silvicultural treatment (after about age 4) would improve log quality from these plantations for solid wood products significantly. This is discussed in detail in Section 7.

The National Farm Forestry Inventory (NFFI) (Wood et al. 2001) reported an estimate of 40, 600 ha of hardwood farm forests established to 2000. The areas of the major species or types are shown in Table 4.3. It cannot be assumed that the areas are being managed for sawlog production.

Table 4.3. Hardwood farm forests, Australia, 2000 (NFFI)

Species or type	Area (ha)	Species or type	Area (ha)
Acacia species	3 056	*E. grandis*	5 594
Corymbia species	718	*E. nitens*	8 877
Eucalyptus cladocalyx	2 145	Other eucalypts	2 955
E. globulus	7 737	Other species and types	9 530

4.3. Potential log availability for solid wood products

There is considerable variation in projected availability of logs suitable for solid wood products. This variation appears to arise from differences in the definition of a sawlog employed by different organisations, and in the projected yield of these logs from particular species, areas and management regimes.

Different silvicultural regimes yield different sizes and quantity of logs, only some of which are suitable for solid wood products. Generally:

- Unthinned and unpruned stands have closely grown trees that yield small, slowly grown stems with a large knotty core and little clear wood.
- Yield from thinned and unpruned stands varies with species. Species that self prune, such as *E. pilularis*, shed their branches as the canopy closes and can produce clear wood. With thinning, the stems increase in diameter and can yield reasonable sawlogs. Species that do not self prune appear to grow larger stems but retain a large knotty core.
- Thinned and pruned stands of any species produce clear wood and can grow large stems relatively quickly.

Figure 4.3. 15-year-old unpruned and unthinned *E. globulus* plantation at Ridgley, Tasmania

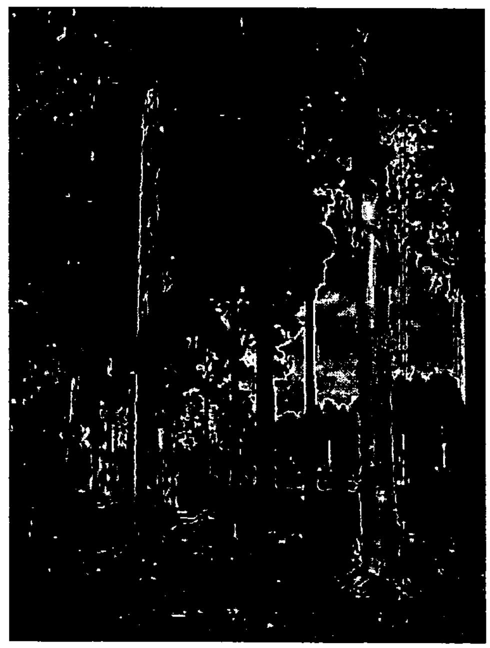


Figure 4.4. 22-year-old pruned and thinned *E. globulus* farm forestry plantation at Busselton, WA (Washusen et al. 2004)

There is also considerable measured and expected variation in the volume and quality of sawlogs from each of these regimes, depending on the species, site quality, timing of the silvicultural interventions, harvest age and other factors. Figures 4.3 and 4.4 show extremes in the resource while Table 4.4 shows estimates of reported log grade recovery for *E. globulus* and *E. nitens* grown under different management regimes. It shows that only 14% of logs from 32-year-old late thinned but unpruned stands could satisfy Victoria's D-grade sawlog specification, while 94% of logs from a 22-year-old thinned and pruned *E. globulus* stand satisfied the same specification.

Projections of expected log grade distributions by species and regimes are not yet available but models are being developed for them.

Table 4.4. Reported log-grade recovery distributions - Victorian DSE grades (Reproduced from Greaves 2004)

forest	sampling strategy	A grade	B grade	C grade	D grade	Below grade	information source
plantation *E. globulus* 22 y.o. **sawlog silviculture** - Western Australia	random	14%	63%	10%	6%	6%	Washusen *et al.* (2004)
plantation *E. globulus* 32 y.o. **pulpwood silviculture** (late thinned age 18) - Gippsland, Victoria	approx. 1:5 selected for quality	0%	2%	7%	5%	86%	Washusen *et al.* (2004)*
plantation *E. nitens* 34 y.o. **pulpwood silviculture** (late thinned age 29) - Gippsland, Victoria	approx. 1:5 selected for quality	0%	3%	5%	5%	87%	Washusen and McCormick (2002)*
natural-stand **regrowth** *E. nitens* - Gippsland, Victoria	selected for quality	22%	63%	10%	5%	-	Washusen and McCormick (2002)

* Reported log grade recovery statistics adjusted for estimated selection intensity applied in log selection

4.3.1. Plantation log availability

Based on the areas of plantations established up to and including 2000, Ferguson et al. (2002) estimated the potential log availability from Australia's plantations to 2044. That work combined available data supplied by plantation owners with indicative regional yield table for plantations where better data were not available. Since that estimate, regional estimates of plantation log supply have become available for publicly owned plantations in Tasmania (Forestry Tasmania 2002) and south east Queensland (DPI Forestry 2003) and for privately owned plantations in Gippsland (MBaC Consulting in prep.). The log availability estimate shown in Figure 4.5 has been developed by combining these sources.

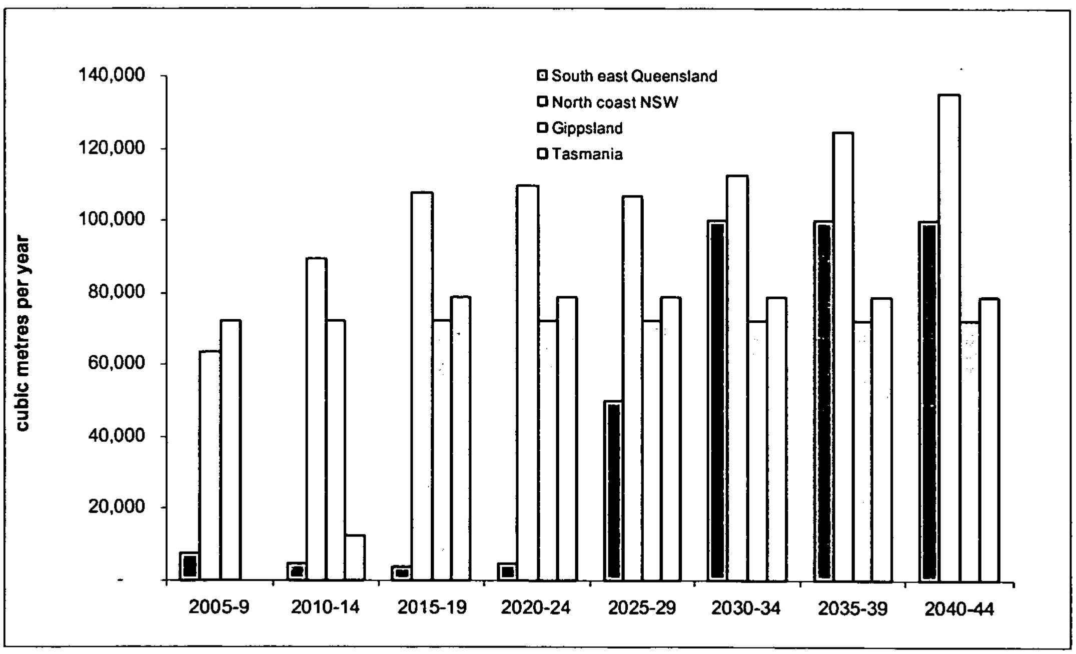


Figure 4.5. Estimate of potential hardwood plantation sawlog availability, 2005-2044

Notes

1. South east Queensland: data to 2024 from Ferguson et al. 2001. Data for 2025 onwards from QDPI Forestry. The estimate for 2030 onwards includes plantations planned to be established between 2004 and 2009.

2. North coast New South Wales: data from Ferguson et al. 2001.
3. Gippsland: Data from MBaC Consulting (in prep.)
4. Tasmania: Data from Forestry Tasmania (2002). These estimates are based on existing and planned new plantations.
5. Brennan et. al (2004) estimated that there are 1080 hectares of hardwood plantations in Western Australia managed for sawlog production. There is inadequate data to develop an estimate of the potential sawlog supply from those plantations.

A major difference between this estimate and Ferguson et al. (2002) appears to be the estimated Tasmanian yield. Ferguson et al. (2002) estimated a peak harvest of over 1 million m^3 of sawlog in Tasmania, while the estimate above, incorporating Forestry Tasmania data, peaks at 80,000 m^3. However, Forestry Tasmania projects availability of more than 1 million m^3 of 'peeler' logs by 2021 (Forestry Tasmania 2002). This is believed to include pruned logs that do not satisfy current sawlog grades, the unpruned part of the stem above the pruned logs, and logs from better unpruned stems.

Total log availability

Plantation hardwoods have been expected to replace log supplies from native forests. However, as shown in Tables 4.5 and 4.6, the estimated sustainable hardwood log availability from Australia's public forest is expected to fall by 36%, or 776,000 m^3, between 2001 and 2039. During the same period, the expected sustainable log yield from private forest is expected to fall by 25% or 115,000 m^3.

Table 4.5. Estimate of sustainable hardwood sawlog availability from public forests, 2001-2039 ('000 cubic metres per year)

State[1]	2000-01[2]	2005-9	2010-14	2015-19	2020-24	2025-29	2030-34	2035-39
WA[3]	471	185	185	185	185	185	185	185
Queensland[4]	186	160	160	160	160	0	0	0
NSW[5]	554	422.5	422.5	422.5	422	422.5	422.5	422.5
Victoria[6]	667	567.5	567.5	567.5	567.5	567.5	567.5	567.5
Tasmania[7]	294	300	287.3	287.3	221	221	221	221
Australia	**2,172**	**1,635**	**1,622.3**	**1,622.3**	**1,556**	**1,396**	**1,396**	**1,396**

Table 4.6. Estimate of sustainable hardwood sawlog availability from private forests, 2001-2039 ('000 cubic metres per year)

State[1]	2000-01[2]	2005-9	2010-14	2015-19	2020-24	2025-29	2030-34	2035-39
Queensland[8]	230	115	115	115	115	115	115	115
NSW[9]	111	111	111	111	111	111	111	111
Tasmania[9]	126	126	126	126	126	126	126	126
Australia	**467**	**352**	**352**	**352**	**352**	**352**	**352**	**352**

Sources
1. Supply from States and Territories not listed is assumed to be negligible.
2. Sources of 2000-01 data: State of the Forests Report 2003; Queensland DPI Forestry Yearbook 2002-03.
3. Source: Conservation Commission of Western Australia, Forest Management Plan 2004-2013.
4. Based on average harvested hardwood volumes reported by Queensland DPI Forestry and assuming that harvesting ceases from 2025.
5. Regional Forest Agreement volumes: Eden 24,000 m^3; Upper North East 109,000 m^3;

Lower North East 160,000; South coast 48,500 m3; Tumut 48,000m3; plus red gum current level 33,000 m3.
6. Source: Victorian Government Policy Statement on Forests, February 2002.
7. Source: Forestry Tasmania: Sustainable high quality sawlog supply from State Forest - Review 2002
8. Sources: South east Queensland regional private native forest inventory project, Bureau of Rural Sciences 2004; 2000-01 volumes assumed to continue for other regions.
9. Assuming that the volumes reported harvested for 2000-01 can be sustained.

The log availability estimates for native forests and plantations are combined in Figure 4.6. It shows that total hardwood sawlog availability is likely to decrease by about 23%, or 635,000 m^3, between 2001 and 2039.

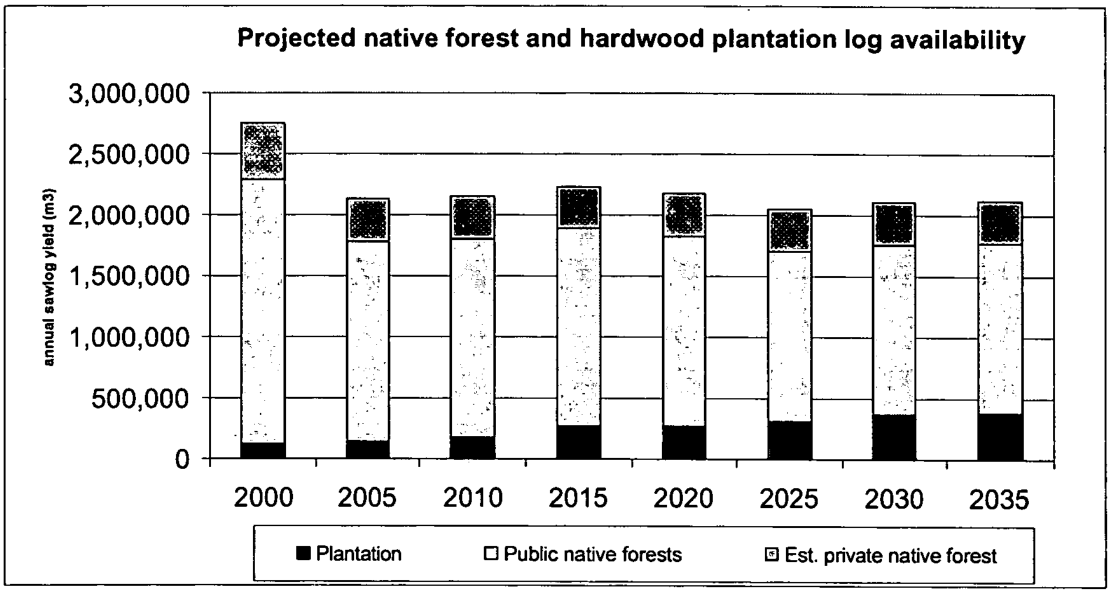


Figure 4.6. Projected native forest and plantation log availability

While there is uncertainty in the projected log availability from plantations, by 2035 plantation hardwood logs are likely to make up:

- less than 15% of the 2001 native forest supply level
- only about 18% of total estimated log availability in 2035
- less than half of the estimated log availability lost from public native forest between 2000 and 2035.

5.0. Processing for solid products

The processing of plantation eucalypt hardwood logs into solid wood products involves:

- harvesting and transport
- pole preparation
- saw milling, including:
    - sawing timber and preparing veneer flitches
    - drying of sawn products
    - dry milling
- veneering. Peeling or slicing veneer flitches or logs and drying the veneer
- gluing
- bio-protection - the preservative treatment of sawn or natural round timber.

5.1. Harvesting and transport

Harvesting and transport is the cutting, sorting and delivery of logs of known species, grade and source to processing mills with minimal physical and drying damage.

Logs are of differing quality and, as shown in Table 7.9, there can be greater variability of plantation trees within a plot than between regions. Therefore, accurate sorting is critical as only logs that meet minimum requirements can be economically processed into solid wood products. Currently, all logs are visually graded at the coupe or log merchandising yard in accordance with established rules. Log graders rely on experience to apply these rules and relate features on the outside of the log to internal grade and value reducing characteristics inside the log. There are techniques being developed to practically determine likely mechanical properties of the wood, such as measuring sound velocity in the log. However, they will not reveal the appearance of the wood.

The usefulness of the current rules in grading plantation logs may be open to question. Washusen (2004a) reports reasonable correlation between the grade assigned under Victorian Department of Environment and Sustainability (DSE) grading rules and recovery of high grade timber. However, he found that the grading system falls down in differentiating between D and below grade. Also, there appears to be some doubt in assessing the size of the knotty core in pruned plantation material. A layer of clear wood can form on logs after they are pruned. This can disguise the existence and size of the knotty core and render conventional external examinations ineffective. To overcome the uncertainly this creates, Hingston (2002) discussed auditing silvicultural practice in plantation stands under a 'Pruned Stand Certification' scheme. A similar scheme has been adopted by some private growers.

5.2. Natural rounds

Plantation hardwoods appear to satisfy the major requirements for poles except durability. They need to be chemically treated if they are to be used externally. Generally, these treatments only penetrate the sapwood of the stem and so the percentage of the post that is fully protected is dependant on the width of the sapwood band. The inner parts of the post are subject to decay in line with the timber's natural durability. However, in the majority of applications, the protected outside sections take the majority of loads while the durability of the remainder may be adequate, especially when compared to exotic softwoods and other alternatives.

As markets for natural rounds offer a substantial potential outlet for plantation thinnings, they can be critical to the economic viability of plantation sawlog regimes, especially in

areas that do not have a ready market for pulpwood. Grant et al. (1998) and Yttrup (2001) tested creosoted NSW species and CCA treated Tasmanian plantation species respectively, and found the structural performance satisfactory over a range of sizes. Similarly, Cookson et al. (2002) found that tress from eucalypt plantations can be successfully converted into vineyard posts. They considered pigment emulsified creosote (PEC) to be the best preservative for this purpose.

Koppers Ltd in Tasmania is currently CCA treating plantation *E. nitens* posts from thinnings and report achieving full penetration of the sapwood band. The posts are being used successfully in orchards, vineyards, piling and general agricultural applications in Tasmania and Victoria. Breakages during installation are reportedly lower than for similar softwood poles. The company plans to treat about 6,000 tonnes of this material in 2005.

5.3. Saw milling

5.3.1. Sawing studies and milling practice

There have been a series of formal research and industry research-in-action trials to assess and recover sawn boards from plantation eucalypt logs. The results have varied considerably with the silvicultural treatment of the resource logs, the target product and the sawing method. The results of formal trials need to be assessed with care. They use different methodologies and report against different grading rules, both between trials and between trials and standard industry practice. This makes comparing these results difficult. On the other hand, industry research-in-action generally uses processes directly comparable to their normal production techniques and their results are tempered by a realistic assessment of the product's acceptance in the market.

Table 5.1 lists Australian companies known to be currently milling plantation hardwoods for sawn timber products. It is not exhaustive. Many in southern Australia are producing relatively low value products from unthinned and unpruned stands. In New South Wales, some high quality products are being recovered from thinned and unpruned stands.

Table 5.1. Australian companies milling plantation hardwoods in mid-2004

Company	Region	Species	Age	Grower	Resource management	Product
Forest Enterprises Australia	North Tasmania	E. nitens thinnings	10-15	FEA	Unthinned, unpruned	Case and pallet timber, dried structural material
Drouin West	Morwell, Victoria	E. regnans sawlog grades	30-40	HVP	Unthinned, unpruned	Mainly structural material, with some appearance
Dormit	Dandenong, Victoria	E. regnans marginal logs	30-40	HVP	Unthinned, unpruned	Pallets
Various millers	Victoria	E. regnans	30-40	HVP	Unthinned, unpruned	Pallets and Industrial wood.
Notaras Pty Ltd	North coast NSW	E. pilularis E. grandis	20-35	SF NSW	Thinned, unpruned	T and G flooring, parquetry
Boral Ltd	North coast NSW	E. pilularis E. grandis	20-35	SF NSW	Thinned, unpruned	T and G Flooring, some structural material
Various millers	North coast NSW	E. pilularis E. grandis	20-35	SF NSW	Thinned, unpruned	Pallets and Industrial wood

Table 5.2. Sawing studies of thinned and pruned material

Species	Location	Age	Trees sampled	Silviculture: thin age (years)	Silviculture: prune age (years)	Reported diameter (cm)[b]		Sawlog fraction	Sawlog fraction C-grade or better	GOSR[c]	Total dry recovery less pallet	Dried select grade recovery	Structural grade recovery: median grade	Structural grade recovery: reject	Information source
E.globulus	Busselton, WA	22	11	3, 5	3, 5, 8	mean sawlog UB for log grades	33-63	66%	100%		22-45%	85-90%			Washusen *et al.* (2004a)
E.globulus	Busselton, WA	22	9	3, 5	3, 5, 8	mean sawlog UB for log grades	33-63	56%	68%		22-45%	85-90%			Washusen *et al.* (2004a)
E.globulus	Busselton, WA	13	55	3, 5	3, 5, 8	mean stand DBH	46	73%		35%		32-54%			Moore et al. (1996)
E. nitens	Otways, Vic	10	9	3,5	3,4,5,6	dbh selected trees	39	60%	NR	41%		>21%			Reid and Washusen (2001)
E. pellita	Innisfail, N.E. Qld	8.5	19	14m, 20m, 5yrs	Unknown pr'd to 3.5m	av DBHUB	24.4	na	na	39	25%	90%			Muneri et al. (when?)
E. urophylla	Innisfail, N.E. Qld	8.5	18	14m, 20m, 5yrs	Unknown pr'd to 3.5m	av DBHUB	24.8			37.3	44%	82%			Muneri et al. (when?)

Table 5.3. Sawing studies of late thinned and pruned material

Species	Location	Age	Trees sampled	Silviculture: thin age (years)	Silviculture: prune age (years)	Reported diameter (cm)[b]		Sawlog fraction	Sawlog fraction C-grade or better	GOSR[c]	Total dry recovery less pallet	Dried select grade recovery	Structural grade recovery: median grade	Structural grade recovery: reject	Information source
E.globulus	East Gippsland, Vic	13	35	8	8	mean sawlog UB	30				>20%				Washusen *et al.* (2004b) *in prep*
E.globulus	East Gippsland, Vic	13	35	8	8	mean sawlog UB	30				>20%				Washusen *et al.* (2004b) *in prep*

Table 5.4. Sawing studies of thinned and unpruned material

Species	Location	Age	Trees sampled	Silviculture: thin age (years)	Silviculture: prune age (years)	Reported diameter (cm)[b]		Sawlog fraction	Sawlog fraction C-grade or better	GOSR[c]	Total dry recovery less pallet	Dried select grade recovery	Structural strength group: median grade	Structural strength group: reject	Information source
E.globulus	Gippsland, Vic	32	30	18		mean sawlog UB for log grades	35-41	20%	45%		23-28%	85-90%			Washusen *et al.* (2004a)
E. nitens	Stanley, Vic	34	20	26		mean sawlog UB for log grades	37-43	20%	8%		17-24%	50-71%			Washusen and McCormick (2002)
E. argophloia	S.W. Qld	10	10	8		Av DBHUB	16.8			0.422	33%	77%			Armstrong 2003b

Table 5.5. Sawing studies of unthinned and unpruned material

Species	Location	Age	Trees sampled	Silviculture: thin age (years)	Silviculture: prune age (years)	Reported diameter (cm)[b]		Sawlog fraction	Sawlog fraction C-grade or better	GOSR[c]	Total dry recovery less pallet	Dried select grade recovery	Structural grade recovery: median grade	Structural grade recovery: reject	Information source
E.globulus	Burnie, Tasmania	33	4	-	-	mean stand DBH	41			26%			F17	46%	Waugh and Yang (1994), Yang and Waugh (1996)
E.globulus	Burnie, Tasmania	21	4	-	-	mean stand DBH	36			28%			F17	31%	Waugh and Yang (1994), Yang and Waugh (1996)
E.globulus	Burnie, Tasmania	19	4	-	-	mean stand dbh	27						F17	58%	Waugh and Yang (1994), Yang and Waugh (1996)
E.globulus	Northern Vic	15	10	-	-	mean sawlog UB	28			>20%	15%	13%			Washusen et al (1998, 2000a)
E.globulus	Gippsland, Vic	24	10	-	-	selected tree mean dbh	40			47%		>10%			Northway and Blakemore (1998)
E.globulus	South west WA bush sites	9		-	-					53%	28%				Brennan et al. (1992)
E. nitens	Mt Beenack, Vic	29	4	-	-	dbh stand	46			47%					Waugh and Yang (1994), Yang and Waugh (1996)
E. nitens	Burnie, Tasmania	24	4	-	-	dbh stand	24			28%					Waugh and Yang (1994), Yang and Waugh (1996)
E. nitens	Burnie, Tasmania	25	4	-	-	dbh stand	15			28%					Waugh and Yang (1994), Yang and Waugh (1996)
Corymbia spp	Lake Hume, NSW	40	10	-	-	mean sawlog UB	39			35%	35%	71%			Washusen et al (1998, 2000b)
E. sideroxylon	Lake Hume, NSW	40	5	-	-	mean sawlog UB	36			35%	28%	50%			Washusen et al (1998, 2000b)
E. sideroxylon	Tarrawingee, Vic	26	5	-	-	mean sawlog UB	33			28%	20%	40%			Washusen et al (1998, 2000b)
E. caldocalyx	Bandiana, Vic	36	5	-	-	mean sawlog UB	33			37%	25%	58%			Washusen *et al* (1998, 2000b)
E. caldocalyx	Earlston, Vic	40	5	-	-	mean sawlog UB	34			35%	28%	64%			Washusen *et al* (1998, 2000b)
E. caldocalyx	Majorca, Vic	100	15	-	-	mean sawlog UB	44				30%	93%			Washusen *et al.* (2003)
E. grandis	Lower Bucca State Forest NSW	7	100	-	-	mean sawlog UB	18.2			50%	12%	12%	SD6 F17		Armstrong (2003)
E. grandis	Lower Bucca State Forest NSW	7	100	-	-	mean sawlog UB	18.2			50%	12%	12%	SD6 F17		Armstrong (2003)
E. pilularis	Conondale S.F. S.E. Qld	32	30	-	-	large end small end (av)	43 23		94%	44.7	78%	94%			Armstrong 2003a
E. cloeziana	South Burnett, Qld	11	4	-	-	Av DBHOB	20			37	24%	19%			Armstrong et al. 2002
E. pilularis	Dandali & Harcourt, N.E. NSW	4	26	-	-	Av DBHOB	16.5			0.34	7060%	63%			Matt Armstrong pers. comm. 2005
E. argophloia	S.W. Qld	32	10			Av DBHUB	38.7			0.474	64%	75%			Armstrong 2003b
Corymbia spp	Argentina	13	6	no	no	Av DBHOB	26.7			0.291	44%	89%			Hopewell 2002
E. cloeziana	Argentina	13	8	no	no	Av DBHOB	26.2			0.339	60%	74%			Hopewell 2002
E. cloeziana	Argentina	14	7	no	no	Av DBHOB	35.1			0.424	54%	87%			Hopewell 2002
E. pellita	Argentina	13	5	no	no	Av DBHOB	-			0.374	58%	94%			Hopewell 2002
E. pellita	Argentina	14	6	no	no	Av DBHOB	-			0.411	30%	88%			Hopewell 2002
E. pilularis	Argentina	14.5	7	no	no	Av DBHOB	-			0.372	55%	90%			Hopewell 2002
E.grandis x E. urophylla	Argentina	12	44	no	no	Av DBHOB	-			0.355	71%	92%			Hopewell 2002

Milling logs from thinned and pruned stands

There appears to be very little pruned and thinned material of the optimal harvest age available nationally, and none appears to be regularly supplied to millers.

There have been relatively few full trials of thinned and pruned stands. Results have generally been positive. The latest trial reported by Washusen *at al.* (2004) using standard industry practice indicates that recoveries may be as good or better than native

forest logs, with little drying or stress induced degrade. The details of the trials are included in Table 5.2. Two trials of late pruned and thinned material are included in Table 5.3. However, this material was harvested relatively shortly after pruning. Note that dried *Select* grade recovery is shown as a percentage of total dry recovery less pallet. It is not a percentage of total recovery from the log.

In pruned stands the recovery of high quality boards is usually dependant on the size of the defect core and log diameter. Figure 5.1 shows the effect of diameter on the recovery in a series of trials conducted with standard industry practice in an existing hardwood mill. In these trials the logs used were managed by similar methods so the defect core was relatively small and uniform in diameter. Large diameter pruned logs under these circumstances can produce high recovery of high quality products. Where pruning is delayed recovery is likely to be reduced.

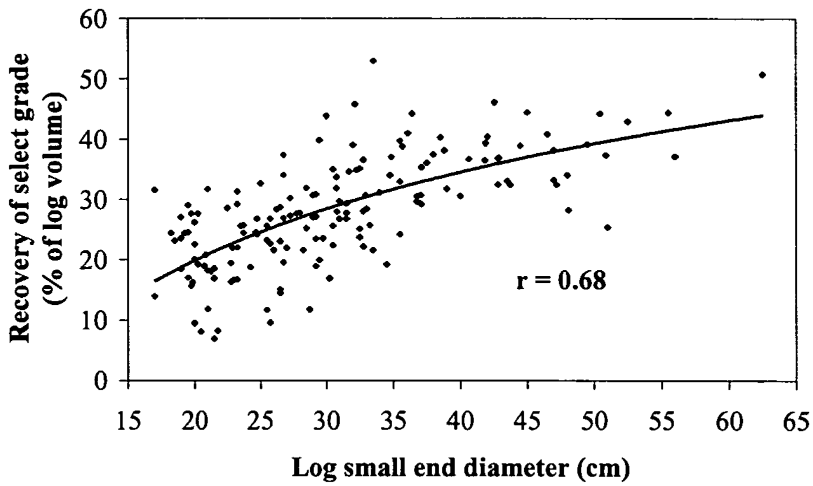


Figure 5.1. Plot of log diameter and recovery for pruned eucalypts processed with standard industry practice (Washusen and Clark, *in prep*)

Other benefits of pruning are that a high percentage of the stand volume will be high quality sawlog and rotation lengths can be reduced significantly. Results from pruned stands may not always be positive, possibly because of species differences. Recent trial results in 17-year-old pruned *E. nitens* grown in the Otways region of Victoria using standard industry practice have been less positive with some decay occurring around pruned branch stubs, the site of wood moth damage and dead epicormics (Washusen unpublished). The full impact of the decay has not yet been quantified, but recoveries will be reduced in comparison to similar grade native forest regrowth *E. nitens* that were also processed in the trials. Pruned Ash eucalypts have also exhibited excessive kino formation, staining and decay.

Milling logs from thinned and unpruned stands

As described above, the quality of thinned and pruned material varies with species. The details of the trials are included in Table 5.4. Care should be taken in interpreting this data as the evaluation methods in these trials vary considerably because of changes in the Australian Standard and because other standards were used such as the FIFWA Standard in Western Australia.

In NSW, logs of an average age of about 30 years from thinned and unpruned State Forest of NSW stands are being processed into some appearance but mainly structural and industrial products. Of approximately 100,000 m^3 harvested, 50% goes to pulpwood, 40% is processed into industrial wood and about 10% is being processed for high value solid products (Robin Heathcote 2004, pers. comm.). Both Boral Ltd and Notaras and

Sons are milling plantation *E. pilularis* and *E. grandis* for appearance timber. After an initial period coming to grips with the material, they are now handling it in a similar manner to native forest logs. They report recoveries are low compared to native material but the material dries satisfactorily if initial drying is closely controlled. The major problems are the prevalence of natural feature, the variability of wood properties that lead to increased distortion in the board, some drying problems and additional costs due to handling and docking an increased number of small, variable grade boards.

Milling logs from unthinned and unpruned stands

There have been a large number of trials of this material using logs from unthinned and unpruned stands that reflect the greater abundance of these types of plantations. Generally the green recovery is satisfactory but grade recovery is often poor, due to the prevalence of feature and losses due to growth stress induced distortion and drying degrade. The details of trials are included in Table 5.5. Of the 30-40 year old sawlog harvested in Victoria, it appears that about 75% of delivered logs are milled for industrial wood with the remainder milled for higher value products. Several firms, including Drouin West Timber Sales Pty Ltd in Victoria, and Forest Enterprises Australia (FEA) in Tasmania, are milling unthinned and unpruned stands commercially, generally producing structural and industrial timber. Drying is a significant problem, especially initial drying. If not carefully controlled, this leads to considerable degrade. Gum vein is reportedly a significant problem in the Victorian *E. regnans*. Internal checking is common in both *E. regnans* and *E. nitens* and can affect up to 50% of pieces.

5.3.2. Market and processing strategies for sawn wood products

Currently there are two distinct market and processing strategies for native forest hardwoods, an appearance product strategy and a structural product strategy. Under an appearance product strategy, the target product is dry and stable sawn timber with low levels of defect or natural characteristic. Log selection and production processes focus on maximising recovery of the highest grade and value of appearance products from the log, not necessarily the highest volume. The relatively high unit cost of production is then met by selling a differentiated product at a relatively high price.

Under a structural product strategy, log selection and production processes focus on maximising volume recovery and minimising the cost in manufacturing a generally dry, stable material. This is essential. Unless it is highly durable, the product has to compete in a commodity market with an established and keenly priced competitor, sawn softwood. If it is highly durable and a low shrinkage, non-collapse prone species, it may be sold unseasoned.

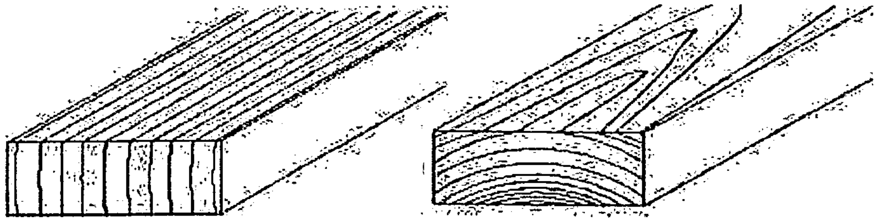
The major technical issues in pursuing either strategy appear to be:

- the sawing pattern required for successful drying particular species
- processing to mitigate the effects of tension wood/growth stress
- drying to reduce unacceptable degrade.

The prevalence of knots and other features in the wood is a natural result of particular species of trees grown under given silvicultural regimes. Processing can only reduce their impact on product acceptability by grading and docking to exclude knotty and featured material.

Sawing strategies

Sawing strategies have a major bearing on processing efficiency, the ability to saw without drying degrade, and end product performance, especially for appearance products. There are two basic approaches: quarter sawing, where the growth rings are generally at right angles to the face of the board, and back sawing, where the growth rings run parallel to the face of the board.

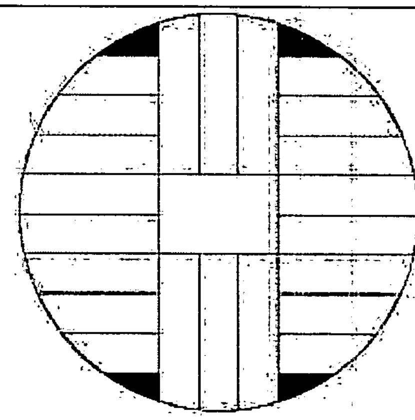
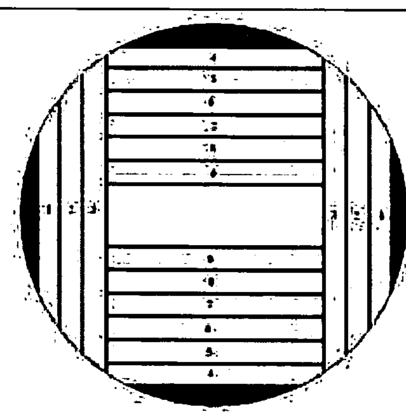


(a) (b)

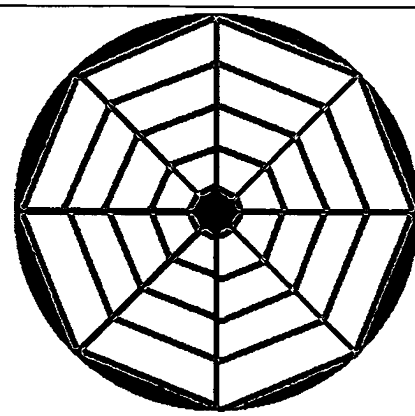
Figure 5.2. Quarter sawn (a) and back sawn (b) boards

The major determining factor in the sawing strategies summarised in Table 5.6 is in the amount of drying defect that can develop during processing. Wood shrinks considerably as it dries and the unit shrinkage is about twice the rate along the line of the growth rings (tangentially) as it is perpendicular to the growth rings (radially). With a quarter sawn board, the higher shrinkage rate is across the shorter dimension of the board. In back sawn boards, the higher shrinkage rate is across the face of the board. In high shrinkage species such as *E. nitens,* this shrinkage in back sawn boards can produce significant drying stresses across the face and lead to surface checks and product down grade.

Table 5.6. Comparison of sawing strategies

Quarter sawing strategy **Recovery:** >40 cm SED moderate-high; <40 cm SED low-moderate. **Advantages:** Surface checking and internal checking is minor in collapse prone species. Can produce thicker boards. Low shrinkage across face of the boards. **Disadvantages:** Greater losses due to growth stress related distortion in small diameter logs. Drying times longer. **Relative cost:** High in small diameter logs.	
Back sawing strategy **Recovery:** >40 cm SED moderate-high; <40 cm SED moderate-high. **Advantages:** Produces wider boards than quarter sawing. Potentially faster log throughput and lower sawing costs. **Disadvantages**: Drying degrade can be high in many eucalypt species. High shrinkage across face of board in some species. **Relative cost:** Low in all diameter classes, very low in high throughput systems. Figure shows log breakdown strategy for 45 cm SED log on twin saw equipped with chippers.	

Radial sawing strategy



Recovery: Very high recovery of radial sawn wedges and high recovery of back sawn boards.

Advantages: For back sawn boards evidence suggests higher recoveries of non-conventional bevelled products than conventional sawing.

Disadvantages: Prototype system has slow throughput. However, there is potential for technical improvement. The pattern illustrated produces high volume of narrow boards suitable from a restricted range of applications.

Relative cost: Uncertain.

Figure adapted from Radial Timber Australia brochure

The sawing strategy selected in production depends on the primary species group and the intended final product. Current practice with native and plantation material of non-collapse prone, low shrinkage species, such as *E. pilularis*, indicates that they can generally be back sawn without significant loss of appearance grade, though back sawn material can be more prone to surface checking (Nolan 2003). Trials in temperate plantation-grown *Corymbia* spp, *E. saligna* and *E. cladocalyx* and other similar density species indicate they can be back sawn successfully without significant loss of appearance grade recovery. Under certain conditions *E. globulus* can also be back sawn and produce grade recovery similar to quarter sawing (Washusen et al. 2004). However, the Forests and Forest Industries Council of Tasmania found that it was not commercially feasible to back saw young Tasmanian regrowth *E. obliqua* (Innes in press).

Current experience for native and plantation material of collapse prone and high shrinkage species, such as *E. nitens*, shows that they should be quarter sawn to regularly produce the best recoveries of appearance grade products. Even though quarter sawing of smaller diameter logs will reduce sawing recovery rates and width recovery of all grades, the recovery of appearance grade boards after drying is improved. It also reduces the unit shrinkage across the wide face of boards in service (Kingston and Risdon 1961), improving timber stability.

For structural products, where drying degrade such as checking is not a major grade determinant, boards of most sizes can be quarter sawn or back sawn.

Tension wood and growth stresses

The success of either sawing strategy is highly dependant on the level of longitudinal tensile growth stress at the stem periphery and/or tension wood severity and volume. Tension wood/growth stresses can have a considerable impact on product recovery, product quality, product sizing accuracy and other processing efficiencies.

Growth stresses and tension wood are often discussed separately in literature. However, recent research has shown that they should be considered together. The major difference between the two is in their definition. Tension wood, according to the International Association of Wood Anatomists, is reaction wood that forms in hardwoods and the physical chemistry of the fibre wall is altered significantly. The result is that the wood produces very high growth stresses and both transverse and longitudinal shrinkage during drying are very much higher than in normal wood. This shrinkage often appears similar to conventional collapse but the cause of the shrinkage is fundamentally different.

In contrast, longitudinal tensile growth stresses are normal in all hardwoods but in normal wood or wood with low volumes of tension wood, the stress levels are

significantly lower than in wood where tension wood severity is high. Drying of normal wood produces much less degrade. Systematic studies of tension wood by ensis-Wood and Fibre Quality, using the SilviScan technology, have commenced in plantation grown *E. globulus*. The prevalence and affect of tension wood on processing is better known for *E. globulus* than for other species. For example, Figures 5.3 and 5.4 show the impact of tension wood on green board distortion and cupping of dried products for logs segregated on tension wood severity.

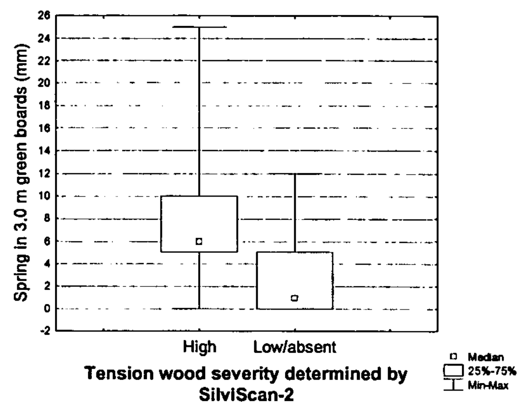


Figure 5.3. Spring in green boards in *E. globulus* logs segregated on tension wood severity (Washusen et al. in prep.)

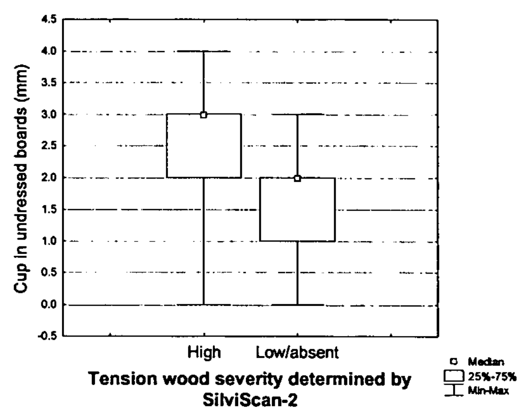


Figure 5.4. Cup in dried undressed *E. globulus* boards after drying in an accelerated drying schedule (Washusen et al. in prep.)

Tension wood occurrence can also be significantly influenced by silviculture. However, in stands where early thinning has been undertaken, the difficulties of tension wood are minimized (Washusen 2002, Washusen et al. 2004). Mitigating the effects of tension wood-induced growth stresses and drying defects during processing is difficult with both back sawing and quarter sawing strategies. A major aim of plantation development should be in the reduction of tension wood severity and within stem volumes.

Mitigating the effects of normal growth stresses.

As shown in Figure 5.5, longitudinal tensile growth stresses are generally at their maximum in the newly formed wood near the bark. They decline and reverse to compression in the older wood, producing a gradient in stress levels from the periphery to the centre of the stem (Hillis 1984). For logs of different diameter with the same magnitude of stress at the periphery, the stress gradient in smaller logs will be steeper. Hence the effects of stress release during sawing are often greater in small diameter logs. Similarly where the radial dimensions of boards are greater, the effect will be more pronounced.

In plantation-grown logs above 40 cm small end diameter, there may be no difference in recovery or product quality for particular species between back sawing and quarter sawing (Washusen et al. 2004, Rotheram personal communication). However, in smaller diameter logs recoveries are reduced when quarter sawing is applied. The sawing configuration that minimises the effects of growth stress and improves recovery generally produces more back sawn or transitional boards.

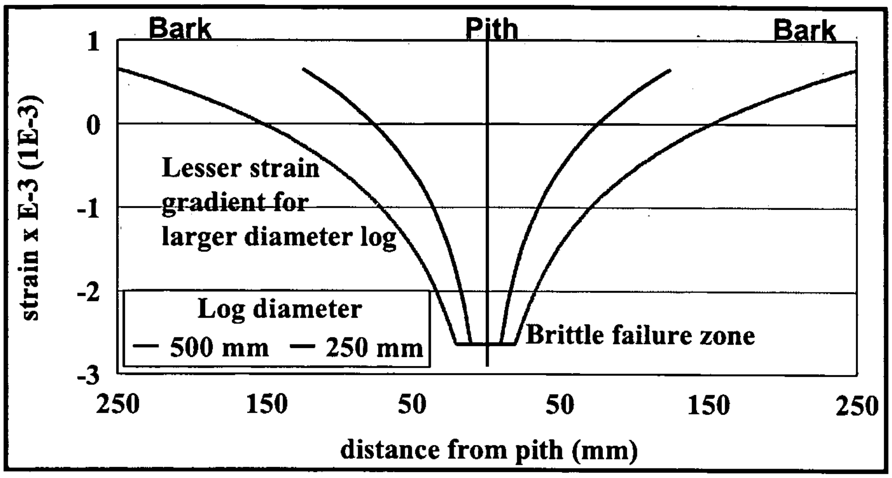


Figure 5.5. Longitudinal strain profile in log originating from growth stress, showing pattern for different sized logs (Waugh 2000 from Kubler 1959)

Log break-down systems and their use

In Australia, hardwood mills usually have sawing systems that have log break-down and resawing stages. Of these two stages, the break-down systems are critical to the sawing process. These log break-down systems are described in general terms below with comments as to their use in plantation-grown and young regrowth resources.

The most common sawing systems operating in Australia are single saw systems coupled with conventional or line-bar carriages that move the log in a reciprocating motion through the saw. These systems have developed around the native forest resource, which produces logs with highly variable quality (including pipe defect) and dimensions. Grade sawing has developed to maximise product quality by taper sawing and by releasing stresses uniformly by rotating logs during processing. However, grade sawing is labour intensive as sawyers must assess the log's visual characteristics between cuts, and vary orientation and sizes to maximise the volume of the most valuable grades and dimension. Logs are usually sawn one board at a time. If they are to operate at maximum efficiency the sawyers must be highly skilled. Single saw systems can apply both back sawing and quarter sawing strategies. They have been applied successfully by existing mills to process plantation grown eucalypts using conventional processing methods including slab and dimension sawing (Washusen and McCormick 2002, Washusen et al. 2003).

Twin saw systems coupled with reciprocating carriages are also common in Australia. A less common variation is the coupling of the twin saws with chippers that significantly increase volume throughput of mills. These systems have potentially higher throughput than single saw systems because two saws are operating simultaneously during log break-down. When chippers are applied they effectively make four cuts. Adaptations such as end-dogging systems with hydraulically operated rotation devices, that allow 90^{o} turn down of the flitch without releasing it, have potential to improve mill throughput rates. Twin saw systems have an added advantage over single saw systems in that they apply a symmetrical cutting pattern that release stresses uniformly and reduce the need to rotate logs. The major disadvantages are that grade sawing is limited and taper sawing cannot

be applied. However, in pruned clear wood eucalypts, there may be no advantage in grade sawing, and if log length is reduced the effect of taper is minimised.

The more sophisticated twin saw systems are best suited to back sawing, although experimental quarter sawing strategies have been applied to plantation-grown eucalypts (Washusen et al. 2004). In less sophisticated systems where one of the saws can be retracted they can be used effectively in quarter sawing.

The only other log break-down system operating in Australia is the prototype radial sawing system. The cutting pattern that this system applies may have recovery advantages over conventional technology. This system is currently being assessed for its potential to process plantation-grown eucalypts in FWPRDC supported research.

Linear sawing systems are another broad group. There are many types available and they are mostly used in softwood processing, although small trials indicate that these systems can potentially process eucalypts. They are distinguished by the absence of the reciprocating carriage, which may produce much higher log throughput rates. They are either twin saw systems coupled with chippers or multi-saw systems coupled with chippers and scribing saws that profile logs prior to sawing. They may have a resawing stage, but often produce dimensioned boards during log breakdown. The elimination of the resawing stage has an added advantage in that back sawn slabs (boards that have been dimensioned in thickness but not width) that require resawing are eliminated. Where slabs are normally produced resawing into more than one board often produces spring during resawing on multi-saws. Two projects supported by JVAP and FWPRDC are currently underway in Australia evaluating the potential for application of linear systems in plantation-eucalypt processing.

Drying

Timber sawn into boards has to be dried to a moisture content suitable for its intended application. Drying appearance hardwoods without unacceptable degrade is a significant challenge. The timber must be dried relatively slowly and with care, or drying degrade and loss of value result (Nolan 2003). Drying structural hardwoods can be significantly easier as some drying-induced degrade, such as surface and internal checks, does not necessarily influence the structural grade. The final product only has to be evenly dried to an acceptable whole and stable product.

Conventional drying (or seasoning) of timber involves two distinct processes: the removal of water from the wood surface and the movement of water from the interior to the surface. The moisture content and drying rate of the surface is controlled by the temperature, humidity and air speed. Most Australian hardwoods have a closed cell structure, with most openings between fibre cells blocked. Water within the cells can only diffuse through the cell walls to escape and evaporate off the surface. This is quite slow. Also, early in conventional drying, the rate of evaporation from the timber surface will exceed the rate of movement of water from the core to the surface. The drying surface wants to shrink over a core that does not and this establishes tension in the surface and compensating compression in the core. If drying is too rapid, the tensile stress on the surface increases above the failure point of the material, and the timber surface splits or checks. For many eucalypt hardwoods, the timber can only sustain relatively moderate conditions without degrade until the centre of all boards is below fibre saturation point (FSP). Drying can then proceed much more quickly under more severe conditions.

Rapid initial drying is also believed responsible for increased internal checking and collapse in collapse prone species such as *E. regnans* and *E. nitens*. Normal collapse can generally be recovered by reconditioning but excessive collapse cannot (Greenhill 1938). Internal checking is an irreversible degrade that is particularly hard to detect, and causes significant problems in young collapse-prone regrowth eucalypts in Victoria and Tasmania, and is prominent in similar plantation species, such as *E. nitens* (Yang et al. 2002a, McKenzie 2003). Internal and surface checking and unrecovered collapse are severely restricted in appearance grade products.

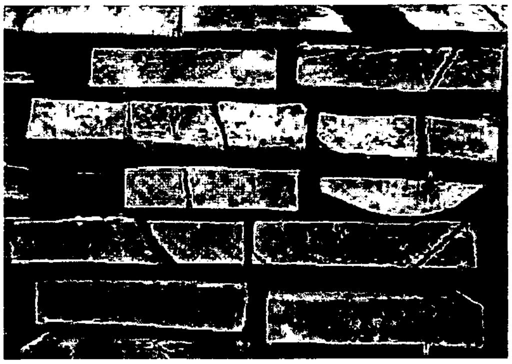


Figure 5.6. Stress and drying induced end split in sawn plantation *E. regnans*

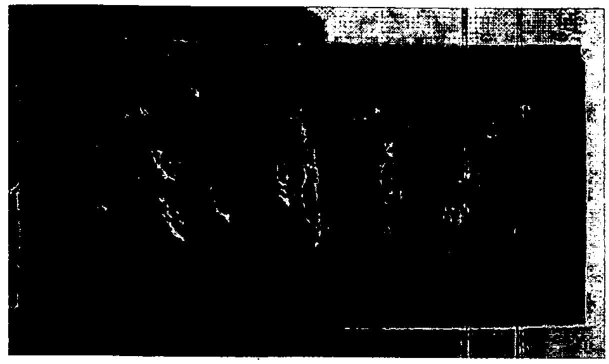


Figure 5.7. Internal check in dry 11-year-old plantation *E. nitens*

The rate that plantation hardwoods can be dried without unacceptable degrade is critical to the economic viability of processing because of its impact on production cost and market opportunity. While it may take up to 12 months to produce a suitably dry hardwood board 38 mm thick, a similar softwood product can be converted from a log and be a dry and stable product in a hardware store in as little as a week.

Limited reported research has focused on drying plantation eucalypts. Northway and Blakemore reported on three FWPRDC projects that investigated accelerated drying schedules of four species for structural hardwood. Appearance recovery was low but *E. grandis*, *E. saligna* and *E. maculata* dried satisfactorily. *E. globulus* developed significant surface checking and collapse (Northway 1996, Northway et al. 1996a, Northway et al. 1996b). Other drying results have generally been reported as part of full milling trials with little specific detail. Reports from industry involved in processing plantation material is that the material appears to be susceptible to considerable drying degrade if initial drying is not carefully controlled. If it is controlled, the material then dries in a similar manner to the native forest material. In many existing hardwood mills, it is dried in racks in the open air, in sheds, or in the controlled conditions of a predryer.

Summary of sawing and processing trials

Generally, the results of processing trials conducted across Australia indicate that the industry is capable of milling several species of plantation-grown eucalypts with a range of sawmilling systems and under different market strategies. However, product recovery and quality has varied considerably. The following conclusions can be drawn from these trials:

1. Knots and other defects associated with branches are major causes for down grade of products for both appearance and structural applications. However, there have been differences between species and plantation age. Pruning substantially improves product quality in all species.
2. Systematic field evaluation and processing trials of *E. globulus* have identified that tension wood is a major impediment to efficient processing and high recoveries of appearance and structural products. The volume, severity and occurrence of tension wood are influenced significantly by plantation silviculture. Tension wood appears to be the cause of excessive growth stresses and poor drying performance and, as a result, elimination of tension wood or reduction in its occurrence and severity will be beneficial to processing. Less is known of the impact of tension wood on other species.
3. End splitting and board distortion due to stress hamper processing efficiencies and may reduce recovery where inappropriate sawing methods are employed.

4. Drying defects in some back sawn timber reduce recovery. This can be mitigated by quarter sawing.
5. Some species such as *Corymbia spp. E. cladocalyx* and *E. saligna* can be successfully back sawn. Some trials indicate that back sawing is possible in species such as *E. globulus* where intensive management with early thinning has been applied.
6. There is potential to reduce processing costs with the application of specialised processing systems. Some research is underway to quantify this.

Dry milling

Dry milling is the machining of rough sawn and dry timber to their final market dimension and shape. Ozarska and Ashley (1998) compared the milling properties of timber from seven plantation-grown species: Rose gum *E. grandis;* Sydney blue gum *E. saligna;* Spotted Gum *Corymbia maculata;* Red gum *E. camuldulensis;* Sugar gum *E. cladocalyx* and Red Ironbark *E. sideroxylon.* They concluded that the timber from these species could be successfully milled for furniture production but that the selection of manufacturing processes was dependant on the species being milled.

5.4. Veneering

Veneering is the peeling of logs or slicing of flitches into sheets or leaves of timber at a pre-determined thickness and grain orientation. Veneer is used as either:

- **decorative product**, usually laid up onto a wood panel such as MDF
- **structural product,** usually assembled into an engineered wood product such as plywood or LVL.

Veneer for structural application is generally peeled, while veneer for decorative applications is peeled or sliced. There have been occasional studies of slicing plantation eucalypts for appearance veneer and these reported high recoveries of face grade from suitably pruned plantation logs (Roper 2000).

There have been several studies of peeling Australian regrowth and plantation grown logs, and overseas plantation eucalypts for structural purposes (Gaunt 2002, Boral Timber Tasmania 2001). Forestry Tasmania has conducted a series of trials overseas peeling both Tasmanian regrowth and plantation *E. globulus* and *E. nitens* for structural and appearance application (Bob Gordon 2004, pers. comm.). Recovery was satisfactory but was about 30-40% higher for the pruned material than the unpruned material. Processing *E. nitens*, Mackenzie (McKenzie 2003) found a more extreme difference with 90% of veneer from unpruned *E. nitens* logs unsuitable for high strength products due to knots and other defects. However, Forestry Tasmania believes that neither of the plantation species were suitable substitutes for native forest grown material as they did not meet requirements for high strength engineered timber products, such as container floors and formwork. Work by Boral on plantation *E. nitens* supported this (Boral Timber Tasmania 2001). The plantation material was satisfactory for other plywood grades.

Big River Timbers in Grafton, NSW have been peeling thinned but unpruned plantation Rose gum *E. grandis* and Blackbutt *E. pilularis* supplied by State Forest of NSW for plywood for some time. They report a lot of 'reactivity' or stress in the wood, an undesirable variation in density from pith to bark, and lower recoveries than native forest logs of the same size. Stress in the wood causes end splits that lead to 'spinout' of the log as it is peeled. Due to the varying properties of the outside leaves (both across the sheet and from one side of the board to the other), they find that plantation plywood tends to bow. They also report that the milled Blackbutt *E. pilularis* yields veneer superior in quality and quantity to the *E. grandis*.

Gluing

Historically, there have been problems with gluing eucalypt hardwoods due to its density, closed cell structure and extractives. Species with a high density and extractive content present the most difficulty. Several companies have trialed purpose-mixed phenolic adhesives and achieved a Type A bond with plantation or young eucalypt material in both Tasmania and NSW. Notwithstanding these results, the Plywood Association of Australia (PAA) feels that caution is needed when comparing isolated commercial testing with the rigorous proving trials necessary before structural eucalypt panels are launched on the Australian market (Andy McNaught 2004, pers. comm.).

Plywood is being successfully and possibly profitably manufactured from unpruned *E. globulus* by an ENCE-owned company in Pontevedra, Galicia, Spain. The logs are peeled without pre-heating. Results from an utilisation trial of plantation-grown *E. nitens* in Spain did not indicate problems with gluing for plywood or solid-wood composites (INFOR 2004). Plywood is also being manufactured from plantation *E. grandis* in South America (Austin 2001).

6.0. Wood quality

Wood quality is the combination of characteristics of the log and properties of its wood that affect the recovery of useful products and their value and serviceability in intended applications (Hillis 2000). These characteristics are not consistent. For any log, they vary with the species of the source tree, its growing conditions and age at harvest, the section of the tree that the log comes from, and the part of the log sampled.

As different wood properties influence aspects of production and use, they can be loosely grouped under four headings, namely: Visual character; Wood properties - Usage; Wood properties - Processing; and Log Characteristic - Form. The groupings are not exclusive and assessment of their importance varies with the stage of production and point of sale. For example, particular characteristics are assessed and valued when the log is graded and sold to a miller. Other characteristics are assessed when the milled timber or veneer is sold to a final customer.

There is considerable detail about particular wood properties in published work and this is summarised in Appendix 4. However, it is rare for them to be assessed comparatively. As part of this review, a list of wood characteristics was prepared and circulated to researchers in four research organisations. They ranked the importance of each characteristic for products and the ability of each species to provide these characteristics. These results have been included in:

- **Table 6.1** that provides a rating of the importance of each property for each major product group
- **Table 6.2** that provides a rating of the likely wood quality to be found in Australia's major plantation species when grown under the three major silvicultural regimes.

6.1. Wood quality and product requirements

Table 6.1 rates the importance of major wood qualities with each major product group. It has been compiled from the contributions of researchers from 3 research organisations active in hardwood processing and use.

Rating legend

5 = Highly desirable / essential	4 = Desirable / required	3 = Preferable	2 = Neutral	1 = Undesirable

Table 6.1. Rating of wood qualities with major product group

Characteristic	Natural rounds	Sawn Appearance	Sawn Structural	Veneer Appearance	Veneer Structural
Visual Character					
Clear wood - present	2.3	3.8	2.5	4.3	2.3
Colour - pale - present	2.0	2.8	2.3	3.0	2.0
Colour consistency - present	2.0	3.8	2.3	4.0	2.3
Gum Vein - kino - present	2.3	1.3	2.0	1.0	2.0
Grain - even	2.0	4.5	2.3	3.8	2.3
Knots - present	1.5	1.3	1.5	1.0	1.8
Insect feature- present	1.8	1.5	1.5	1.3	2.0

Characteristic	Natural rounds	Sawn Appearance	Sawn Structural	Veneer Appearance	Veneer Structural
Wood Properties - Usage					
Density - high	3.3	3.3	3.8	2.0	2.3
Hardness - high	2.5	3.5	3.3	3.0	3.0
Joint Group	3.0	3.3	3.5	2.3	2.5
Stiffness - SD4 pref.	3.5	3.0	4.0	2.8	3.8
Strength - SD4 pref.	3.5	3.0	4.0	2.8	3.8
Durability - high	4.8	3.0	4.0	2.5	3.3
Preservative retention - high	4.5	2.5	3.5	2.3	3.5
Lyctus resistant sapwood	3.8	4.0	3.5	4.3	3.8
Gluability - high	3.5	4.5	3.8	4.8	4.8
Workability Machining - high	3.5	4.8	3.8	3.8	3.8
Fire Performance	3.3	2.8	3.3	2.8	3.0
Microfibril angle	2.5	2.5	2.8	2.3	2.8
Stability - high	4.0	4.8	3.8	3.8	3.8
Wood Properties-Processing					
Shrinkage - low	2.5	4.5	3.5	3.5	3.5
Shrinkage ratio - tangential/radial	2.5	3.8	2.5	2.3	2.3
Collapse - low	2.3	4.5	3.3	4.3	3.8
Internal checking - low	2.5	5.0	3.8	4.3	3.0
Surface checking - low	3.0	4.8	3.3	4.3	2.5
Tension wood - low	3.8	4.8	4.5	4.5	4.5
Growth strain - low	3.8	4.8	4.0	4.0	3.8
Log characteristic - Form					
Heartwood content - high	3.0	3.5	3.3	3.7	3.3
Sapwood thickness - (mm) - low	2.8	3.4	3.0	3.5	3.3
Heart / Corewood diameter - low	3.0	3.2	2.7	3.0	3.0
Knotty core diameter - small	3.0	5.0	4.0	4.7	4.3
Log form - taper - low	3.3	4.0	3.5	4.0	4.0
branch frequency - low	4.0	4.8	3.8	4.5	4.0
Decay - low	4.8	4.8	4.5	4.8	4.0
End split - low	4.3	4.0	4.0	4.0	4.0

6.2. Wood quality, species and silviculture

Species grown under various silvicultural regimes produce wood of a particular quality. Table 6.2 rates the likely wood quality of major plantation species for sawn appearance products when grown under the three major silvicultural regimes:

- sawlog managed plantation stands (thinned and pruned) in the column headed with a 'S'
- mixed plantation stands (thinned or wide spaces and unpruned) in the column headed with a 'M'
- fibre managed plantation stands (unthinned and unpruned) in the column headed with a 'P'.

It has been compiled from the contributions of researchers from three research organizations active in hardwood processing and use.

Rating legend

5 = Excellent	4 = Very good	3 = Good/ Satisfactory	2 = Poor	1 = Very poor

Table 6.2. Rating of likely wood quality by species and silviculture

Characteristic	Shining gum *E. nitens;*			Southern blue gum *E. globulus;*			Messmate *E. obliqua.*			Blackbutt *E. pilularis;*			Spotted gum *C. citriodora, C. maculata;*			Dunn's white gum *E. dunnii;*			Gympie messmate *E. cloeziana.*			Sydney blue gum *E. saligna;*			Sugar gum *E. cladocalyx.*		
	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P
Visual Character																											
Clear wood	3	4	2	4	4	3	2		2	4	2.5	2	1.5	3.7	2		4		4	2.5	2	4		3	3	4	
Colour - pale	5	5	5	4	4	4	3		3	3	3	3	3	3			4					3.5		3	3	2	
Colour consistency	5	5	5	3.5	4	3.5	3		3	3	2.5	2.5	2.7	2.7	2.5		4		2.5	2.5	2.5	3.5		3	3	3	

Characteristic	Shining gum *E. nitens;*			Southern blue gum *E. globulus;*			Messmate *E. obliqua.*			Blackbutt *E. pilularis;*			Spotted gum *C. citriodora, C. maculata;*			Dunn's white gum *E. dunnii;*			Gympie messmate *E. cloeziana.*			Sydney blue gum *E. saligna;*			Sugar gum *E. cladocalyx.*		
	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P
Gum Vein - kino	5	5	5	4.5	5	4	2		2	4	3	3	4	3.5	2		5		4	3	3	4		5	3	5	
Grain	5	5	5	3.5	4	3.5	4		4	3	3	3	4	4	3		4		3	3	3	4		5	3	4	
Knots	4	3	1	4.5	3	2.5	5		2	4	2.5	2	1.5	3.2	2		3		4	2.5	2	4		2	3	4	
Insect feature	1			3		3				3	3	3	3	3	3				3	3	3	3			3		
Wood Properties - Usage																											
Density	2		3	3.5	4	4				4	4	4	4	4	4		3		4	4	4	3.5		4	4	5	
Hardness				3		3				4	4	4	4	4	4				4	4	4	3			5		
Joint Group				3		3				4	4	4	4	4	4				4	4	4	3			4		
Stiffness				3		3				4	2.5	2	4	3.2	2				4	2.5	2	3		4	5	4	
Strength				3		3				4	2.5	2	4	3.2	2				4	2.5	2	3		4	5	4	
Durability				3		3				4	4	4	4	4	4				4	4	4	3			5		
Preservative retention				3		3				4	4	4	4	4	4				4	4	4	3			2		
Lyctus resistant sapwood	2	2	2	2	2	2	2		4	5	5	5	1.5	1.5	1				5	5	5	2		2	2	2	
Gluability				3		4				3	3	3	3	2.5	3				3	3	3	3		4	3	2	
Workability Machining				3		3.5				3	3	3	3	3.5	3				3	3	3	3		4	3	4	
Fire performance				2		3								4								2		4	2	4	

Characteristic	Shining gum *E. nitens;*			Southern blue gum *E. globulus;*			Messmate *E. obliqua.*			Blackbutt *E. pilularis;*			Spotted gum *C. citriodora, C. maculata;*			Dunn's white gum *E. dunnii;*			Gympie messmate *E. cloeziana.*			Sydney blue gum *E. saligna;*			Sugar gum *E. cladocalyx.*		
	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P
Microfibril angle (degrees)						3				3	3	3	3	3	3				3	3	3			4		3	
Stability				3		3.5								4								3		4	3	4	
Wood Properties-Processing																											
Shrinkage	3	4	3	3.5	3	3			3	3	3	3	2.5	2.5	3				3	3	3	3		3	3	3	
Shrinkage ratio - tangential/radial	3	3	3	3	3	3			3	3	3	3	3.5	3.5	4				4	4	4	3		3	3	3	
Collapse	2	3	3	2.5	3	2.5			3	3	3	3	4.5	4.5	4				4	4	4	3.5		4	3	5	
Internal checking	2	3	3	3.5	3	2.5			3	4	4	4	4.5	4.5	4				4	4	4	3.5		4	3	5	
Surface checking	2	3	2	3.5	3	2.5			3	4	4	4	4.5	4.5	4				4	4	4	3.5		4	3	3	
Tension wood				3		2				3	2.5	2	4	3.7	2				3	2.5	2	3			3	5	
Growth strain - low growth stress	4	4	3	3	3	2.5			3				3	3								3		3	3	3	
Log characteristic - Form																											
Heartwood content				3		3				3	3	3	3	3	3				3	3	3	3			3		
Sapwood thickness - (mm)	3	3	3	3	3	3			3	3	3	3	3	3	3				3	3	3	3		3	3	3	
Heart / Corewood	2	3	2	3	3	2.5			2	4	2.5	2	4.5	3.7	2				4	2.5	2	3.5		3	3	5	

Characteristic	Shining gum *E. nitens;*			Southern blue gum *E. globulus;*			Messmate *E. obliqua.*			Blackbutt *E. pilularis;*			Spotted gum *C. citriodora, C. maculata;*			Dunn's white gum *E. dunnii;*			Gympie messmate *E. cloeziana.*			Sydney blue gum *E. saligna;*			Sugar gum *E. cladocalyx.*		
	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P	S	M	P
diameter																						5					
Knotty core diameter	2	3	1	3	3	2.5			2	4	3	3	1.5	4	3				4	3	3	3		3	3	5	
Log form - stem taper	4	4	4	3.5	4	3.5			4	4	2.5	2	1.5	3.7	2				4	2.5	2	4		5	3	2	
Branch frequency	3	3	1	3.5	3	2.5			2	4	3	3	1.5	3.5	3				4	3	3	3.5		2	3	3	
Decay	2	3	2	3.5	3	3			2	3	3	3	1.5	4.5	4				4	4	4	3.5		4	3	5	
End split	3	3	2	3.5	3	2.5			2				3	3								3		2	3	3	

7.0. Silviculture

Plantation grown trees are not all the same. Trees may differ because they are of different genetic background (between or within species), have been grown to different ages, are grown in different environments, or have been managed differently over their growing life. And even with all these factors being constant (same species, same age, same environment and same management) grown trees still differ from tree to tree.

This section explores silvicultural influences on the quality of plantation-grown eucalypts using experimental or predicted results sourced from many sources and involving many species. There is considerable variation in many characteristics between species, and results reported for one species may not necessarily apply to another, just as reported results from one site may not apply to another site. The results reported here were selected because they serve to depict relationships (or not) between silvicultural variables and the properties of the grown trees.

7.1. Sources of variation in grown wood

In order to understand how the qualities of grown trees can be improved or controlled to provide a suitable resource for solid wood products, it is important to understand the sources of variation between grown trees:

- between and within species
- with age
- between sites
- within a stand
- with management/silviculture
- with propagation system (seedling, 'clonal')
- within a tree.

7.2. Variation between species and within species: 'genetics'

7.2.1. Variation between species

There is considerable evidence that some species are more suitable as cropped species than others, both for growth rate and for characteristics such as 'suitability for producing sawn timber'. See Figure 7.1. Critical wood properties also vary with species, for example: density (Figure 7.2), MOE and MOR (Ozarska and Ashley 1998), and suitability for moulding (Ozarska and Ashley 1998).

Figure 7.1. Relative growth performance (relative to the trial mean) and estimated fraction of trees within each species that might be suitable for producing sawn timber at the Branxholm site (Victoria) - pruned treatments only (based upon data reported by Bird 2000).

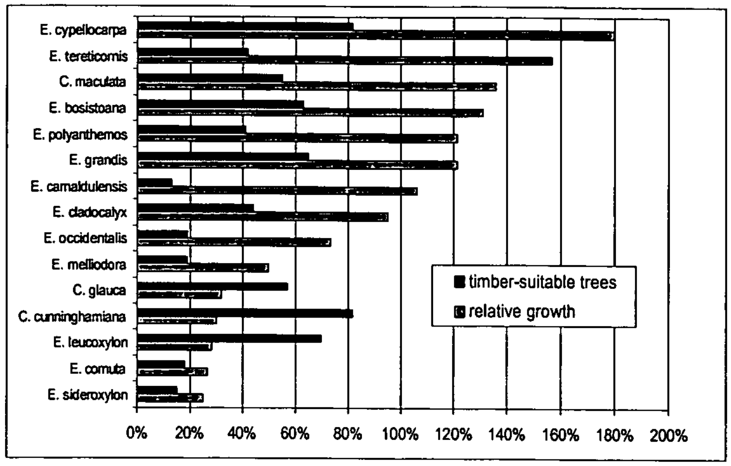
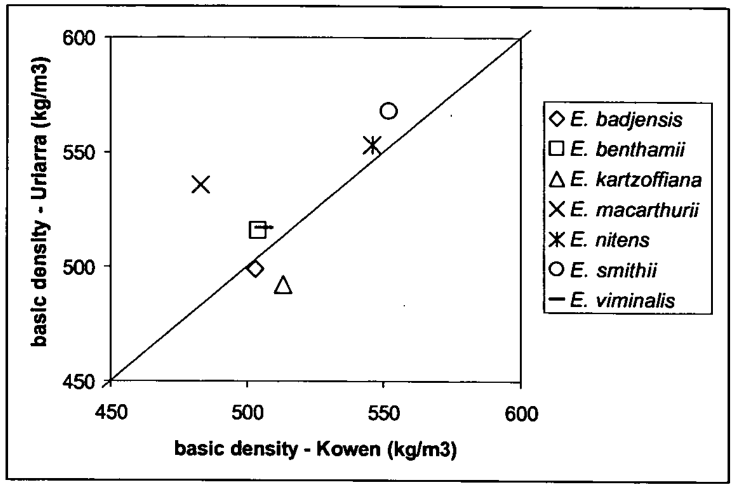


Figure 7.2. Average basic density by species by site. After results reported by Hicks and Clark (2001)



The most suitable species can vary across sites and the best species for one site may not be the best species for another site - e.g. Figure 7.3 (growth) and 7.2 (density).

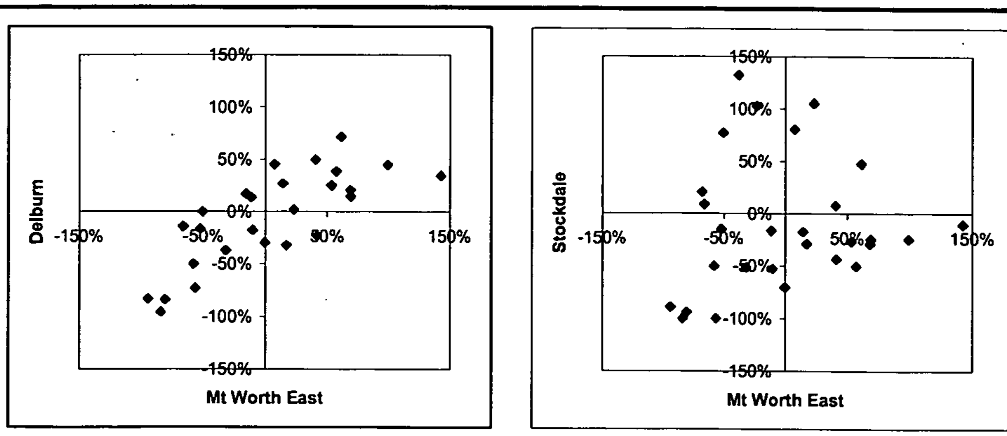


Figure 7.3. Comparing species growth performance across sites in Gippsland, Victoria - one point represents one specie, each axis represents species growth on one site, expressed as a percentage of trial mean growth. Data reproduced from Duncan et al. (2000).

Table 7.1 lists relative attributes of major eucalypt species available for plantations (in Tasmania), and Table 7.2 lists the suitability of species for various solid-wood products. Information regarding grown species was compiled from various sources. A reduced subset of compiled information is included in Appendix 3.

Table 7.1. Relative attributes of major eucalypt species available for plantations (in Tasmania). Table and caption reproduced from Wood et al. (in prep) Table 2 citing Neilsen (1990)

attribute	species				
	E. nitens	*E.globulus*	*E. regnans*	*E. obliqua*	*E. delegatensis*
Ease of propagation	2a	2	2	1	2
Growth rate potential	3	3	3	2	1
Response to low fertility	1	2	0	1	1
Frost tolerance	3	0	2	2	3
Drought tolerance	2	3	1	2	1
Resistance to water logging	1	1	0	0	0
Insect resistance	1b	2	0	1	1
Browsing resistance	1	1	1	2	2
Branch shedding	1	3	2	2	2
Solid wood quality	2	1c	3	3	2
Plantation suitability	Yd	Y	Yd	Yd	N

0-3 performance rating; 0 unsatisfactory, 1 poor, 2 satisfactory and 3 very good. apaper-pot seedlings much easier than open-root, blong term effects still to be determined, cyoung trees may be suitable though yet to be verified, dnot yet verified. Table does not imply equal weighting given that certain attributes may be over-riding. After Neilsen (1990).

Table 7.2. Product suitability by species (Waugh 1996)

species	suitability for					
	round timbers	sawn appearance (furniture)	sawn engineering	engineering veneer	fibre composites	pulp and paper
Casuarina cunninghamiana	*	*	n.s.	n.s.	n.s.	n.s.
E. botryoides	*	*	?	**	**	*
E. camaldulensis	**	*	**	n.s.	n.s.	n.s.
E. globulus	*	*	***	*	**	***
E. grandis	**	**	**	***	**	**
Corymbia maculata	***	**	***	**	*	**
E. muelleriana	***	?	?	?	?	?
E. nitens	*	**	*	**	**	**
E. regnans	*	*	*	**	**	**
E. viminalis	?	*	?	?	?	***
P. radiata	*	*	*	*	***	***

key: *** = very good; ** = good; * = acceptable; ? = no reliable data; n.s. = unacceptable

Variation in pulping properties between species

Pulping and paper-making quality will be an important consideration when selecting solid wood species if a commercial fibre crop is to be harvested as a thinning operation. Hicks and Clark (2001) report pulpwood quality of 13 eucalypt species with potential for farm forestry.

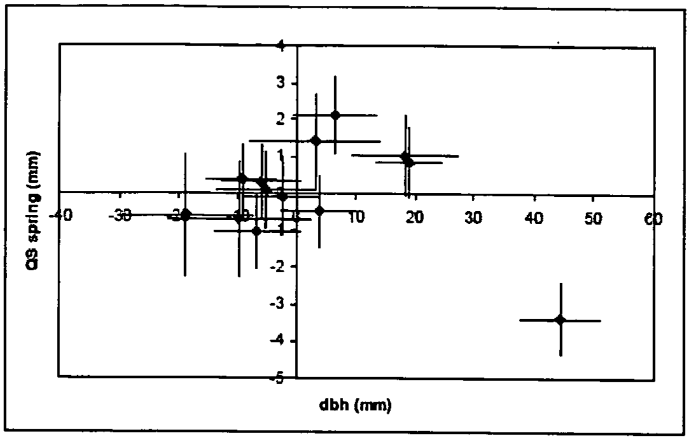
7.2.2. Variation within species

Variation within species can be broadly considered at two levels:

- variation between provenances, sub-species or sub-races within species
- variation between trees within a provenance, sub-species or sub-race.

Variation between provenances, sub-species or sub-races within species
With many tree characteristics there are considerable differences between performance of seed sourced from different locations in the natural distribution - e.g. Figure 7.4.

Figure 7.4. Comparing surface mean values of spring in green quarter sawn boards (QS spring) and dbh - error bars represent plus and minus one standard error. *E. globulus*, age 15 years, north west Tasmania. Figure and caption reproduced from Greaves et al. (2004a), Figure 8



Variation within provenance, sub-species or sub-race within species
The degree of exploitable genetic variation within a sub-race, or within a population generally, is described by two genetic parameters:

- the amount of underlying genetic variation that can be exploited when selected parent trees are cross-pollinated - expressed as the additive coefficient of variation ($CV_a = \sqrt{\sigma_a^2} / \bar{x}$ where σ_a^2 is the additive genetic variance and $\bar{x}$ is the mean)
- the accuracy of selecting superior trees for breeding based upon their observed performance (fast growth, high density, etc.) - expressed as individual/narrow-sense heritability ('heritability', h^2) being how closely variation in phenotypes reflects variation in additive genotypes.

Figure 7.5 depicts observed variation in cup-on-drying of back sawn boards and Figure 7.6 depicts observed variation in tangential shrinkage/collapse - both in six-year-old *E. globulus*.

Figure 7.7 and 7.8 depict spring in green quarter sawn boards in 6-year-old and 15-year-old unthinned *E. globulus*. Quarter sawn boards cut from sawlog-managed stands of *E. globulus* appear to have considerably less spring than boards cut from unthinned stands (Washusen et al. 2004). The stresses leading to spring in green quarter sawn boards appear to relax if a quarter sawn bark-to-bark slab is dried before being centre-cut (Figure 7.8).

Figure 7.5. Variation in cup in air-dried back sawn boards (dried without restraint) *E. globulus* age 6 years Western Australia. Figure and caption reproduced from Greaves et al. (2004a), Figure 3

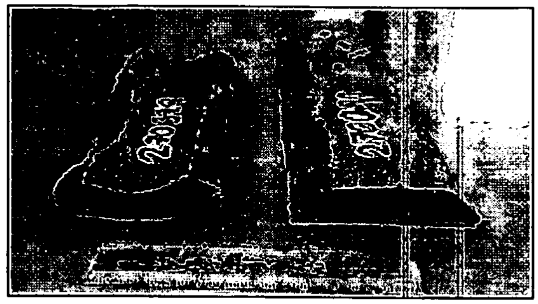


Figure 7.6. Variation in the size of the gap that appeared when the disks were oven-dried (at 104°C) (OD T-shrinkage) - observed variation could be the result of variation in both tangential shrinkage and in the strength of the fibre structure to resist formation of a crack when dried (age 6 *E. globulus*). Figure and caption reproduced from Greaves et al. (2004a), Figure 4

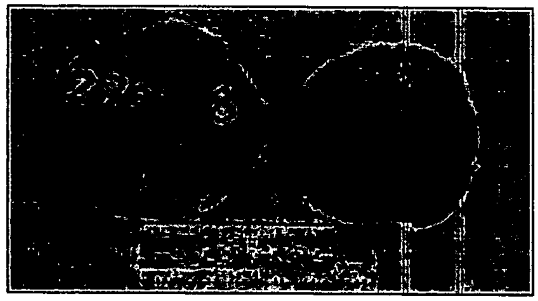
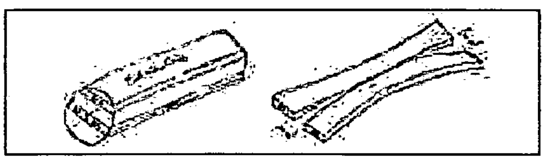


Figure 7.7. Spring in green quarter sawn boards (QS spring) - samples are matched bark to pith: pith to bark as they were in the log (age 6 *E. globulus*). Figure and caption reproduced from Greaves et al. (2004a), Figures 4 and 1



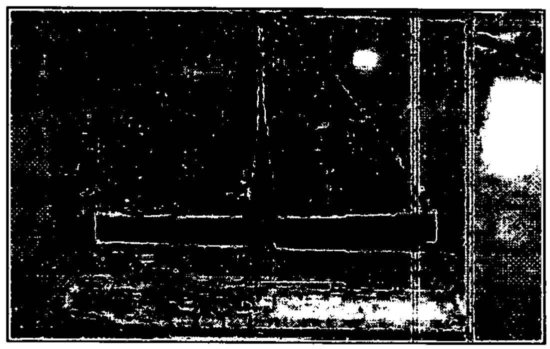
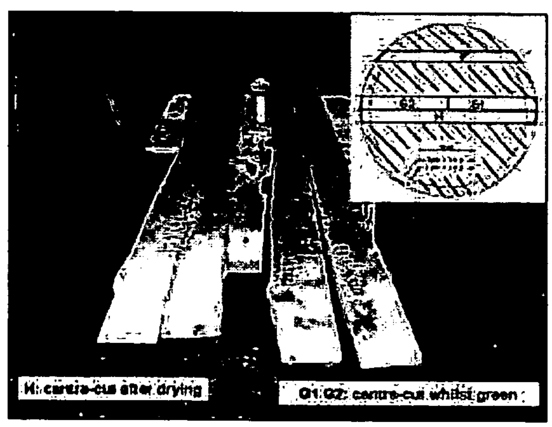


Figure 7.8. Spring in quarter sawn boards centre-cut after drying (left) and centre-cut whilst green (right) samples are matched bark to pith: pith to bark as they were in the log (age 15 *E. globulus*, unthinned pulpwood silviculture). (Figure Bruce Greaves)



7.2.3 Breeding to improve tree quality

Average tree quality can be improved through breeding by selecting a set of high-quality individuals from a population, collecting pollen from some to pollinate flowers of others, and growing the resulting seeds which will produce, on average, higher quality trees.

Tree quality can be defined in terms of properties of the tree that influence either the costs of growing and processing, or the value of products produced:

- log size
- sizes of the knotty core
- size of the juvenile-wood core
- impact resistance (Janka hardness) may have value for flooring applications
- the degree to which back sawn boards surface check and/or cup
- the degree to which internal-checks occur
- wood strength and stiffness
- wood colour
- the ability of the tree to grow in adverse conditions (cold, water-stress, salinity), and resist diseases and pests

There appear to be no available estimates of the relative importance of the various tree characteristics (above) for solid wood applications. Methodology for estimating relative trait values was applied to *E. globulus* for kraft-pulp production systems by Borralho et al. (1993), and Greaves et al. (2004b) reports progress towards estimating selection-trait weights for solid wood utilisation systems. Raymond et al. (2000) compiled a table linking the tree characteristics to products (sawn timber and composites), and Table 6.3 (above) refined the work of Raymond et al. (2000) for sawn-timber utilisation systems.

There is still a pressing need to quantify 'quality' so that tree improvement efforts, both breeding and silviculture, can maximise gains in quality.

7.2.4 Estimating gain due to selection of superior genetic material

The gain that can be made due to (phenotypic) selection of superior individuals from a population is estimated after $G = i\sqrt{h^2}CV_a$ where: G is the gain as a fraction of the mean, and i is the selection differential associated with the fraction of the population selected (1.76 for selection of 1 in 10, 2.67 for 1:100 and 3.37 for 1:1000). Other methods of selection (combined-index or BLUP) will more accurately select winners from phenotypic information, but are beyond the scope of this review.

The intensity of selection that can be applied when making selections is a function of the size of the breeding population required (e.g. 100), the size of the population that can be selected from, and the cost of assessment. In some cases the destructiveness of assessment may be an issue.

Table 7.3 presents a list of possible selection traits which might be considered options for assessment in breeding programs, including assumed genetic parameters and assessment costs and the estimated gain from uni-trait phenotypic selection of 10 trees from a population of 1000.

Table 7.3. Possible selection traits in *E. globulus* - best estimates/guesses of genetic coefficient of variation, heritability, assessment cost and estimated gain from uni-trait selection of 1:100. No indicator of estimate reliability is provided, and whilst some are based upon field measurements, others are based upon little more than considered opinion. Table and figure reproduced from Greaves et al. (2004b), Table 2

selection trait	unit	description	tree average	between-tree CVa	h2	assessment costs per tree	assessment costs 1000 trees	gain: uni-trait selection 10:1000
dbh	cm		25	15%	0.15	$0.5	$500	16%
branch score	1-6 score	6 is best	3.5	10%	0.2	$0.5	$500	12%
branch size	cm	average age 6	10	10%	0.2	$1.0	$1,000	12%
form	1-6 score	6 is best	3.5	10%	0.2	$0.5	$500	12%
taper	mm/m		10	5%	0.1	$1.0	$1,000	4%
pilodyn	mm/m		12	8%	0.4	$3.0	$3,000	14%
SWV		non-destructive	1	4%	0.4	$30	$30,000	7%
core basic density	t/m3	core	0.54	4%	0.4	$22	$22,000	7%
core collapse		core	1	4%	0.3	$22	$22,000	6%
S:G ratio		one core?	2.5	1.5%	0.5	$342	$342,000	3%
nira cellulose content			0.5	1.5%	0.3	$52	$52,000	2%
silviscan traits			1	4%	0.3	$312	$312,000	6%
kraft pulp yield			0.5	1.5%	0.5	$1,030	$1,030,000	3%
decay trait			1	5%	0.2	$40	$40,000	6%
warp: back-sawn cup			1	5%	0.1	$110	$110,000	4%
warp: quarter-sawn spring			15	5%	0.5	$105	$105,000	9%
MOE and MOR		destructive tree sample	1	5%	0.4	$150	$150,000	8%
hardness/impact resistance			1	5%	0.3	$110	$110,000	7%
tangential shrinkage			1	5%	0.3	$140	$140,000	7%
colour			1	5%	0.3	$110	$110,000	7%
checking			1	5%	0.3	$110	$110,000	7%
drying rate			1	5%	0.3	$120	$120,000	7%
tension wood	score ?	propensity	1	5%	0.3	$62	$62,000	7%

Note that the 'silviscan traits' in Table 7.3 refer to assessment of a number of traits simultaneously using ensis-Wood-and-fibre-quality's SilviScan wood property assessment system. SilviScan can measure MFA, density, MOE, cellulose crystallite width (*E. globulus*), fibre dimensions and a number of paper properties and a number of other traits are currently being validated. These traits may differ in heritability and degree of genetic variation. SilviScan assessment costs vary with the number of traits measured and the intensity of measurement.

Table 7.4 presents a compiled summary of reported heritabilities for characteristics of *E. globulus* (Potts 2004).

Table 7.4. Reported heritabilities for *E. globulus* (reproduced from Potts and Vaillancourt 2004)

Trait N h2	N	h2op (range)	cited by	Information sources
Cellulose content	1	0.84±0.27	Potts (2004)	Apiolaza *et al.* unpubl.
Flowering time	4	0.68 (0.60-0.81)	Potts (2004)	Gore and Potts 1995, Apiolaza *et al.* 2001
Vegetative phase change	2	0.54 (0.46 - 0.63)	Potts (2004)	Dutkowski and Potts 1999, Jordan *et al.* 1999, Jordan *et al.* 2000
Frost resistance	1	0.52 (0.017)	Potts (2004)	Tibbits *et al.* unpubl. (seedling T50)
Wood density (Pilodyn)	5	0.46 (0.21 - 0.59)	Potts (2004)	Muneri and Raymond 2001; Apiolaza *et al.* unpubl.
Predicted pulp yield	2	0.46 (0.42-0.49)	Potts (2004)	Muneri and Raymond 2001; Apiolaza *et al.* unpubl.
Flowering precocity	3	0.44 (0.37 - 0.50)	Potts (2004)	Chambers *et al.* 1997, Dutkowski and Potts 1999, Jordan *et al.* 1999
Bark thickness	5	0.42 (0.22 – 0.71)	Potts (2004)	Dutkowski and Potts 1999
Lignotuber development	2	0.35 (0.27-0.43)	Potts (2004)	Whittock *et al.* 2003
Juvenile leaf morphology	5	0.32 (0.13-0.46)	Potts (2004)	Potts and Jordan 1994a, Dutkowski and Potts 1999
Growth (2-8yr)	22	0.28 (0.17 - 0.39)	Potts (2004)	Potts and Jordan 1994b, Borralho *et al.* 1995, Borralho and Potts 1996, McDonald *et al.* 1997, Dutkowski and Potts 1999
Survival (8yr)	5	0.27 (0.14 - 0.41)	Potts (2004)	Chambers *et al.* 1996, Dutkowski and Potts 1999
Microfibril angle	1	0.27±0.24	Potts (2004)	Apiolaza *et al.* unpubl.
Herbivory	4	0.23 (0.00-0.46)	Potts (2004)	Jones and Potts 2000, Jordan *et al.* 2002, O'Reilly-Wapstra *et al.* 2001
Fibre length	1	0.16±0.17	Potts (2004)	Apiolaza *et al.* unpubl.
Coppicing	1	0.07	Potts (2004)	Whittock *et al.* 2003

7.3. Variation with age

Most wood properties vary with tree age:

- Whole-tree basic density increases with age (Figure 7.9)
- The proportion of higher value logs increases with age (e.g. Figure 7.10).

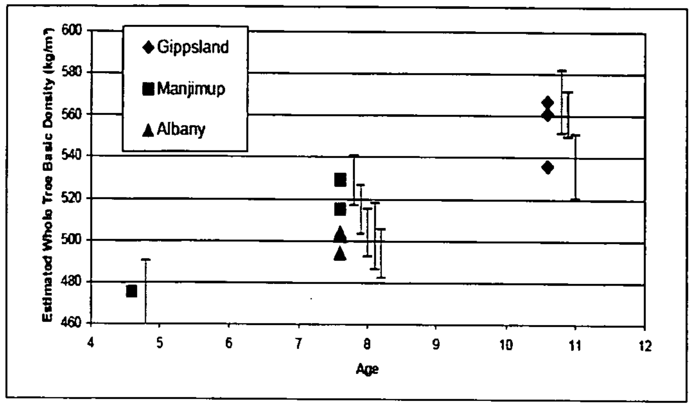


Figure 7.9. *E. globulus* estimated-average tree-farm whole-tree density with age. One point represents one tree-farm. The error bars are approximate 95% confidence intervals (depicted to the right of the mean symbols for clarity) - Figure and caption reproduced from Greaves et al. (2004c), Figure 1

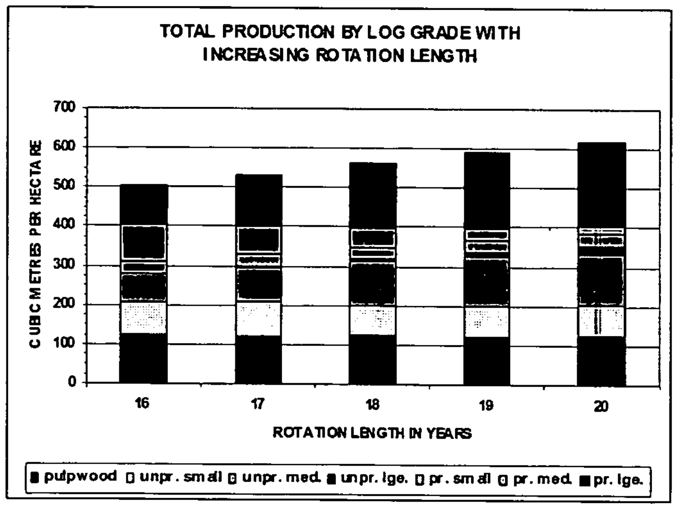


Figure 7.10. Expected log-grade outturn with age for managed-for-sawlog plantations of *E. grandis* in Uruguay. Figure reproduced from presentation by Shield (2004)

Other properties that are thought to vary with the age of the deposited wood, and thus influence average tree properties with age are:

- fibre length
- microfibril angle
- cellulose crystallite width
- Modulus of Elasticity (MOE)
- Modulus of Rupture (MOR).

7.4. Variation between sites

The selection of site probably has influence on most, if not all, of the properties of the growing wood. Most apparent are the differences in growth rate between sites (e.g. considerable differences in Mean Annual Increment between sites for *E. nitens* grown in Tasmania - Table 7.5). Figure 7.11 depicts site averages for wood properties critical for

utilisation for solid wood applications for sub-tropical eucalypts across four sites in Brazil.

Table 7.5. Summary statistics for *E. nitens* plantations at St. Helens, Scottsdale and Dover - Tasmania. Table and caption reproduced from Medhurst and Beadle (2000) - Table 1

	St. Helens	Scottsdale	Dover
Mean annual rainfall (mm)	776	1055	1086
Mean daily temperature range (°C)	7.4–18.4	6.8–17.2	3.3–19.5
Altitude (m; asl)	120	220	110
Trees/ha at planting	1143	1389	1430
MAI[a] of unthinned control at age 9 years (m^3 ha^{-1} yr^{-1})	10.0	26.2	19.7

[a]mean annual increment

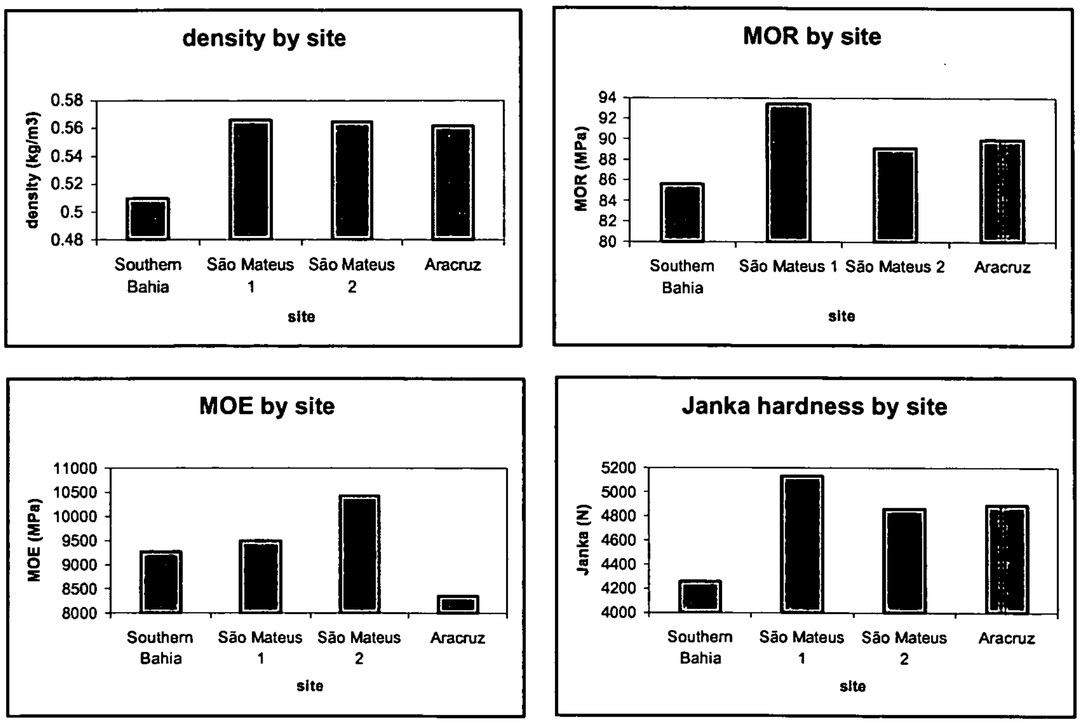


Figure 7.11. Variation with site: *Eucalyptus grandis* x *urophylla* clones: density, mean lower-tree modulus of rupture and modulus of elasticity in static bending and Janka hardness. Growing at four sites in Brazil. Mean values for 26 clones. Reproduced from data reported by Lima et al. (2000)

Factors such as longitudinal growth stress, degree of log end-split, and sawn-volume loss due to distortion were observed to vary across sites where Spotted gum *Corymbia maculata/citriodora* was growing in Queensland (Matt Armstrong seminar, Hardwoods Queensland, QDPI CD-ROM).

In addition, pulpwood properties vary with site and drought. Clark, Read and Vinden (1999) observed trends that pulp yield and fibre length decreased and basic density increased when diameter growth was reduced due to drought.

7.5. Variation with propagation system

During the course of research for this report, no reported variation in wood properties with propagation system in eucalypts were found, although some must exist.

"The basic density of eucalypt coppice material has been found to be lower than that of the first rotation material (5%, Sesbou and Nepveu 1991; 8%, Ferrari 1993). However, the coppice material assessed was younger than the original stem material when tested (Sesbou and Nepveu 1991), or as in the case of Ferrari (1993), the coppice growth had not been thinned." (Whittock et al. 2004)

Vegetatively propagated *Pinus radiata* (from cuttings) has better stem-form and higher density than *P. radiata* grown from seedlings.

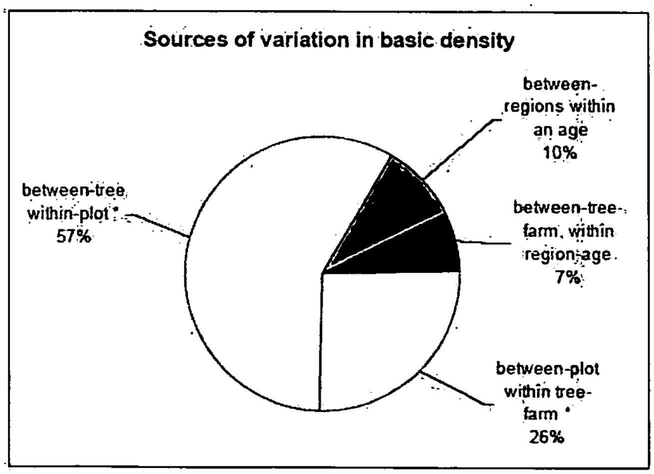
Some species of eucalypt grow well from cuttings, and stands established from a single clone can show considerably less variation between trees. This could have significant value in utilising the stand for solid wood products: less variation may make for easier and more efficient conversion.

Some species are difficult to vegetatively propagate and may still show considerable within-clone variation (e.g. *E. globulus*). ENCE (Spain) is currently establishing only clonal *E. globulus* in southern Spain, where significant gains have been made through clonal selection towards increased growth rate and resistance to wood boring insects. Current silviculture and utilisation is fibre-directed. CMPC (Chile) has produced clonal hybrids of *E. globulus* and *E. nitens* which show high growth, *E. globulus*-like wood properties and *E. nitens*-like resistance to frost. CMPC eucalypt deployment (*E. globulus* and *E. nitens*) is still largely seedling-based. Current silviculture and utilisation is fibre-directed.

7.6. Variation within a stand

Most properties show considerable variation between trees within a stand, particularly for non-clonal stands. Figure 7.12 depicts the magnitude of sources of variation in basic density of *E. globulus* growing in southern Australia, showing that most of the variation is between trees at a location. Figure 7.13 depicts observed variation in growth stresses between five 12-year-old *E. grandis* trees growing on the same site.

Figure 7.12. Basic density of *E. globulus* (1.3m height core density) - sources of variation in operational plantations (* indicates significantly different from zero - percentages are % of estimated total variance). Figure and caption reproduced from Greaves et al. (2004c)



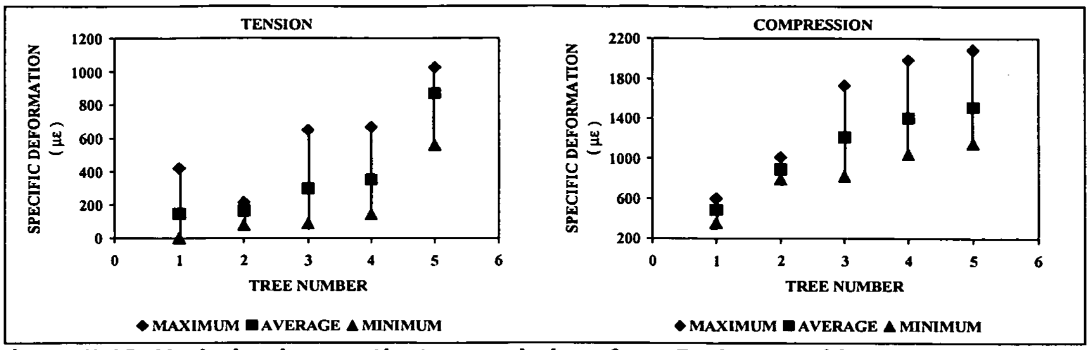


Figure 7.13. Variation in growth stresses in logs from 5 12-year-old trees sourced from fast growing run-of-the-bush *E. grandis* plantations. Figure reproduced from Tomaselli (2000), Figure 4

7.7. Variation with management/silviculture

The properties of grown wood are influenced strongly by conditions under which the trees are grown. The following sections summarise observed influences of management practices on the properties of grown wood:

- Tree spacing
- Site preparation
- Fertilising
- Weed Control
- Thinning
- Pruning
- Reducing growth stress.

7.7.1. Tree spacing

Tree spacing influences both the growth of individual trees and the total growth of the stand. Tree spacing is defined by the initial planting density (and by changes in stand density due to thinning, which is discussed later).

In general, lower stocking results in:

- reduced stand growth rate (Mean Annual Increment is reduced) (Figure 7.14, 7.15)
- increased individual-tree growth: larger trees (Figure 7.14, 7.15), and taller trees (Figure 7.14), although opinions differ and seemingly accepted wisdom is that lower stocking results in shorter trees
- reduced pith-to-bark basic density change gradient, resulting in greater volume of relatively radially-uniform wood (Figure 7.16)
- bigger branches (Figure 7.17)
- lower height to the base of the green crown at a given age (Figure 7.18)
- reduced wastage when thinning commercially (Figure 7.19)
- reduced log quality for a given log diameter **for unpruned stands** (Figure 7.20)
- tree form may be reduced.

Figure 7.14. Spotted gum, *Corymbia maculata* age 11 years: DBH, Height and MAI versus initial spacing, Ipswich, Queensland. Figure reproduced from Geoff Dickinson presentation- QFRI CD

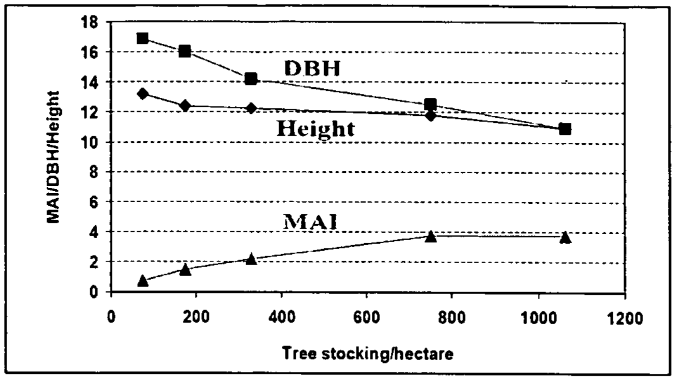
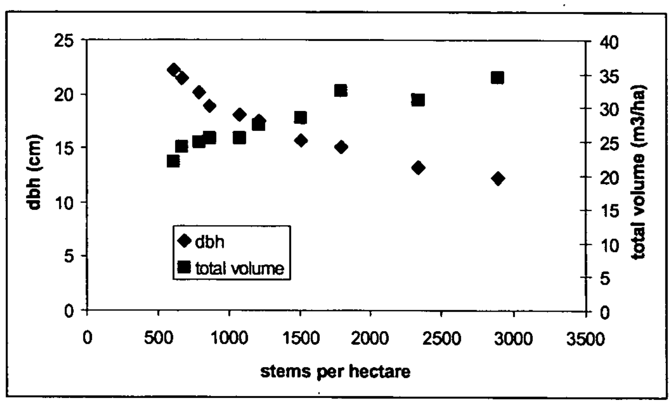


Figure 7.15. *E. nitens*, age 7 years - average diameter and total stand volume with stems per hectare - data after INFOR 2002 Report 165, Table 21



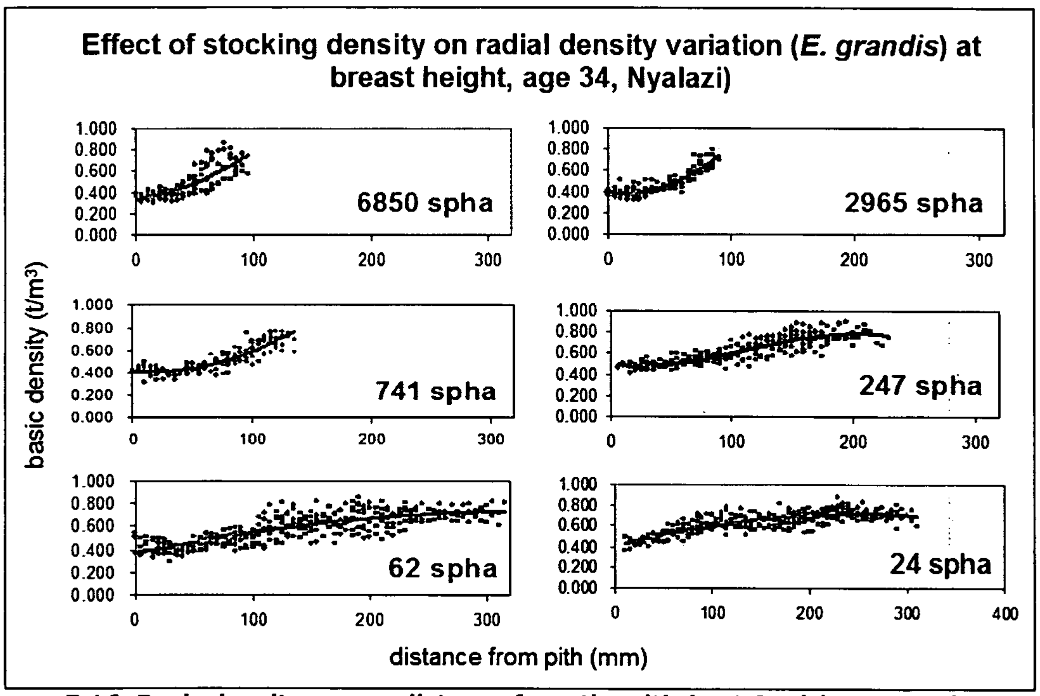


Figure 7.16. Basic density versus distance from the pith (at 1.3 m) in *E. grandis* at age 34 years, by initial stocking in CCT spacing trial at Nyalazi, South Africa. Figure provided by Francois Malan (2005) reflecting a study he undertook with Marianne Hoon

Figure 7.17. Mean number of branches > 35 mm, in the first 6m of stem, by stand stocking relationship, at age 5 years, for *E. nitens* plots planted at various stockings (after Neilsen and Gerrand 1999) - figure and caption reproduced from Neilsen and Pinkard (2000), Figure 2

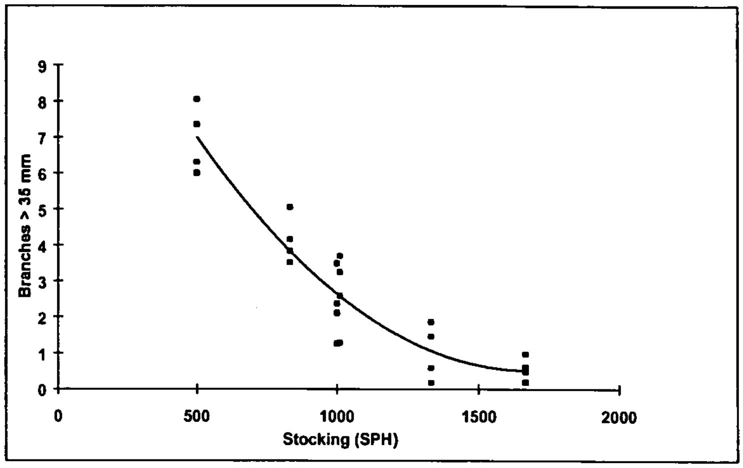


Figure 7.18. Effect of tree stocking rate on height to the bottom of the green crown of *Eucalyptus pilularis*, *E. grandis* (from Kearney 1999) and *E. nitens* (from Neilsen and Gerrand 1999) crown at age 5 - figure and caption reproduced from Montagu et al. 2003a, Figure 1

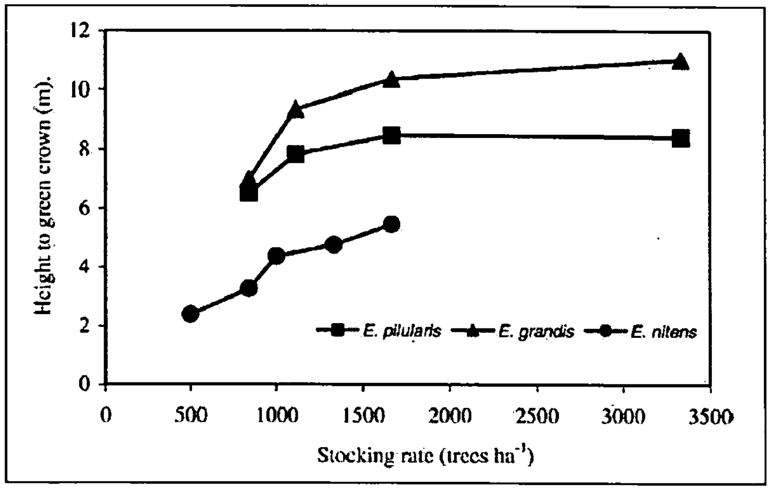


Figure 7.19. Total volume, merchantable volume and volume retained in the selected 300 SPH at age 7 years for stands planted at different stockings. Figure and caption reproduced from Neilsen and Pinkard (2000), Figure 1

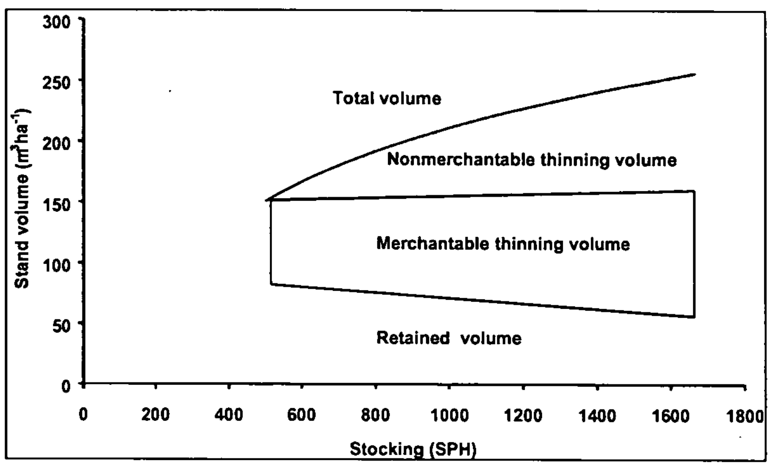
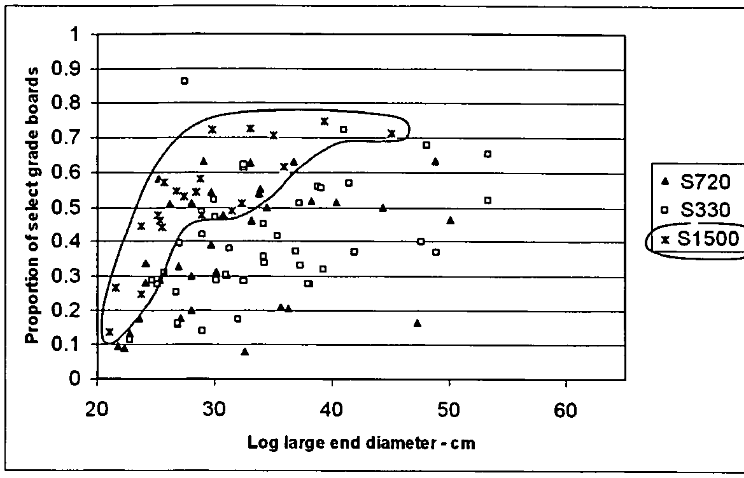


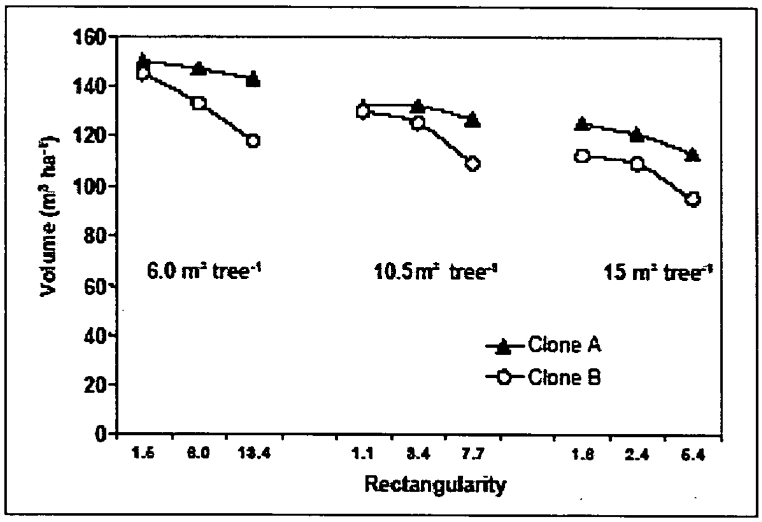
Figure 7.20. Proportion of recovered sawn-boards (100x25mm) that were graded as *Select* grade, by log diameter and initial stocking treatment - 36-year-old *E. pilularis*. Figure reproduced from Muneri et al. (2003), Figure 11

Indicative red boundary line depicts log set from highest initial stocking treatment (S1500)



Uniformity of spacing also influences stand growth rate - the rectangularity of spacing, being the ratio between inter-row and inter-plant-within-row distances, can influence total stand growth for a given total stocking rate (Figure 7.21).

Figure 7.21. Total stem volume at 4 years of age of two *E. grandis x urophylla* clones in Sao Paulo State, Brazil, at a range of initial spacing and rectangularities (the ratio between inter-row and interplant distances) (Stape, unpublished data). Figure and caption reproduced from Goncalves et al. 2004 - Figure 3



7.7.2. Site preparation

Preparation of the site for plantation establishment influences growth rate, and possibly wood properties:

- Retention of slash from the previous rotation (or land-use) can increase stand growth (Figure 7.22).
- Cultivation can increase stand growth, although the value of cultivation is site dependent (Figure 7.23).
- Weed control may be the single most important establishment practice (Bird 2000), with demonstrated value towards stand growth on most sites (Figure 7.24).
- The influence on productivity of fertiliser application is dependent upon the availability of nutrients on any given site - there is no benefit of adding fertiliser if a site is not nutrient deficient. Figures 7.25 and 7.26 depict fertiliser effects on

growth across multiple sites. The effect of fertiliser on growth may also be dependent upon the number of stems per hectare (Figure 7.27).

- The influence of fertiliser on basic density is site dependent but seemingly important on some sites (Figure 7.28).

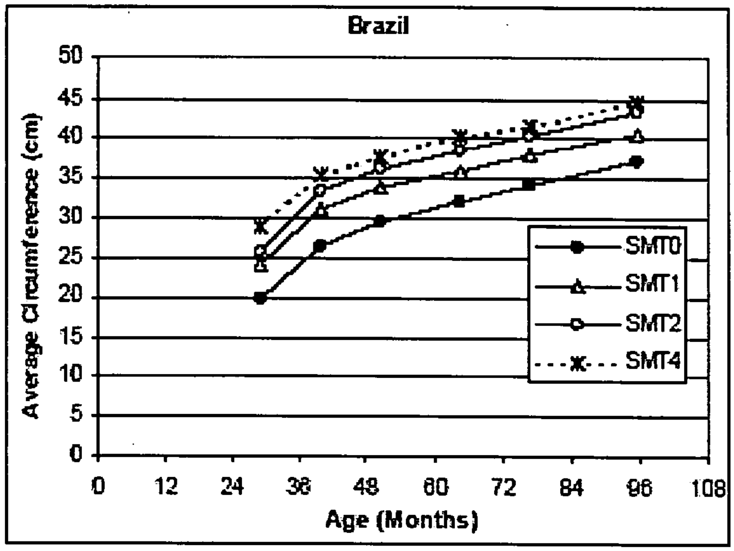


Figure 7.22. Mean stem circumference with age and slash management treatment (SMT0 total slash removal; SMT1 stem-wood and bark removed; SMT2 only stem-wood removal, and SMT4 stem-wood removed and remaining slash burned). Figure and caption reproduced from Saint-André et al. (2004), Figure 3

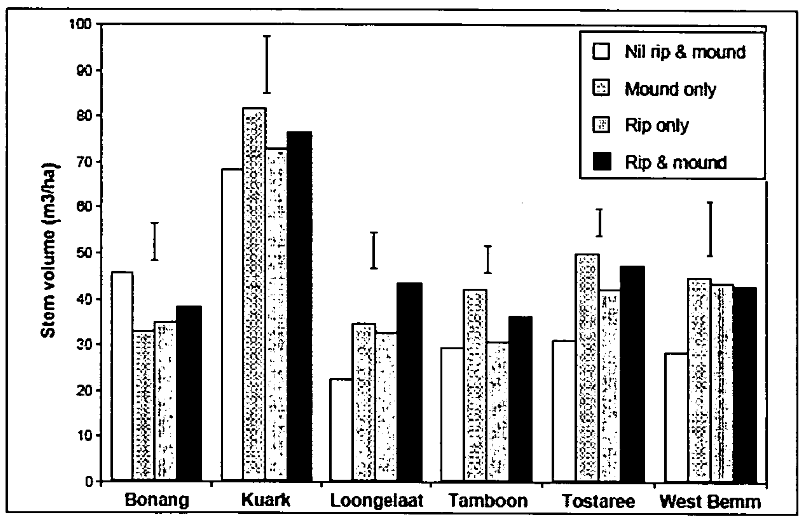


Figure 7.23. Mean stem volume of Eucalyptus spp. at age 5 years in response to cultivation treatments. Data are averages across all levels of weed control and fertiliser treatments. Bars represent LSD (P<0.05). Figure and caption reproduced from Duncan and Baker (2004), Figure 3

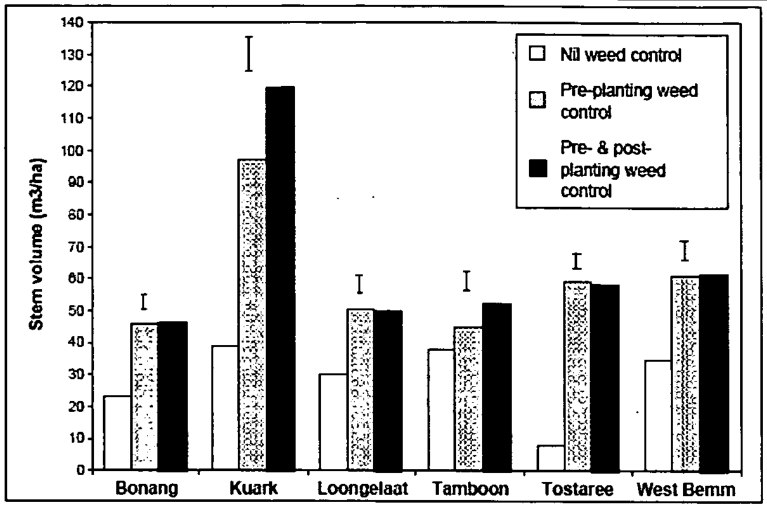


Figure 7.24 Mean stem volume of Eucalyptus spp. at age 5 years in response to weed control treatments. Data are averages across all levels of cultivation and fertiliser treatments. Bars represent LSD (P<0.05). Figure and caption reproduced from Duncan and Baker (2004), Figure 1

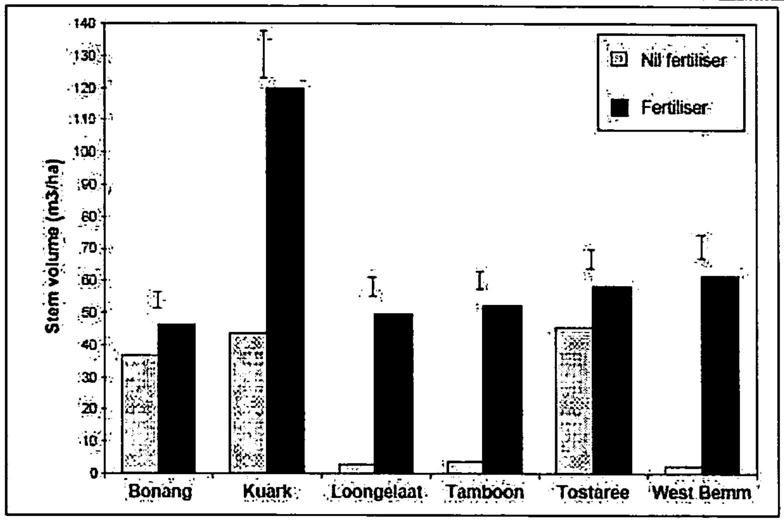


Figure 7.25. Mean stem volume of Eucalyptus spp. at age 5 years in response to fertiliser treatments. Data are averages across all levels of cultivation and weed control treatments. Bars represent LSD (P<0.05). Figure and caption reproduced from Duncan and Baker (2004), Figure 2

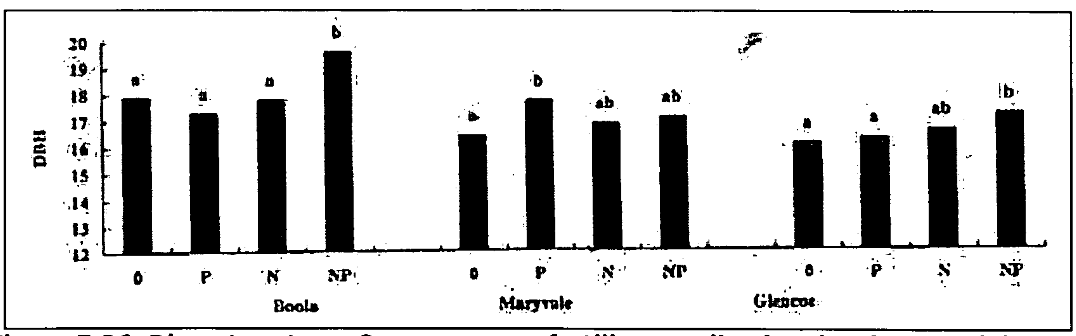
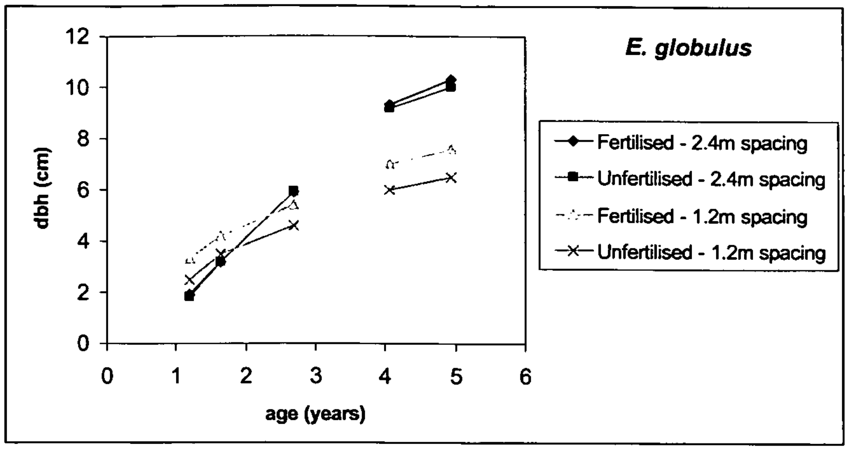


Figure 7.26. Diameter at age 8 years versus fertiliser application, by site - *E. globulus* - 0=control, P=phosphorus, N=nitrogen. Figure reproduced from Raymond and Muneri (2000), Figure 1c

Figure 7.27. *E. globulus* dbh with age by initial spacing (2.4m = 1,736 sph., 1.2m = 6,944 sph) and fertiliser application - data from Sheriff (1998)



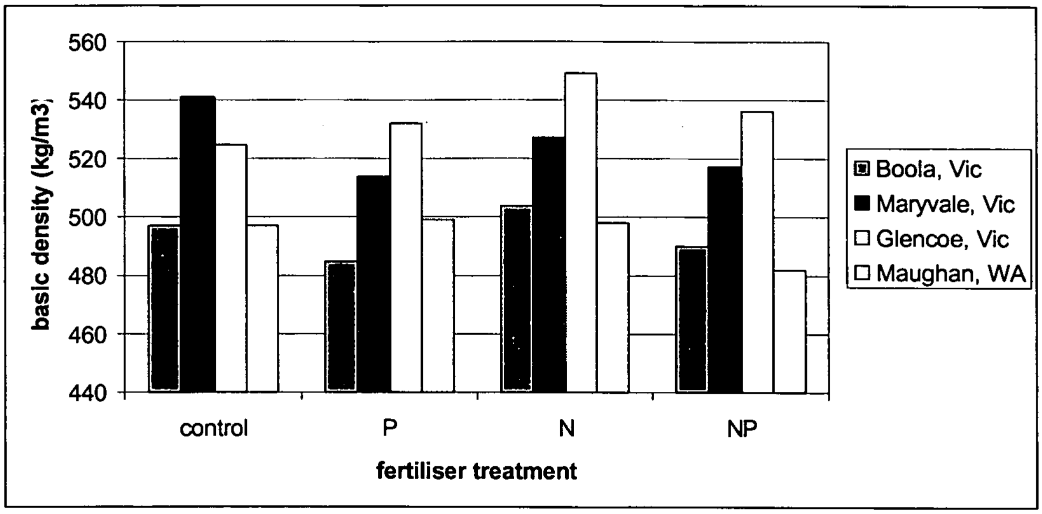


Figure 7.28. Basic density at age 8 years versus fertiliser application, by site - *E. globulus*. P=phosphorus, N=nitrogen. After data reported in Raymond and Muneri (2000), Table 4

7.7.3. Thinning

In general, thinning will reduce total stand growth, but increase growth of individual retained trees. Thinning promotes leaf area growth in the middle and lower canopy (Figure 7.29) and increased photosynthetic rates in the upper and middle canopy (Figure 7.30) (Medhurst and Beadle 2000). Dominant trees in a stand produce more wood per unit of leaf area index (the total area of leaves per horizontal unit area of ground) than suppressed trees (Figure 7.31 after Binkley and Stape 2004 - presentation).

The effects of thinning are dependent upon timing and intensity. In general, greater thinning intensity (less retained stems) results in:

- reduced stand growth (Figure 7.32)
- increased growth of individual retained trees (Figures 7.33)
- development of bigger branches on retained trees (Dickinson et al. 2004)
- greater butt taper of retained trees (Figure 7.34)
- increased end-splitting (Malan and Hoon 1992 - *E. grandis*; Muneri et al. 2003 - *E. pilularis*)

- higher basic density (Figures 7.35 and 7.36)
- greater sapwood thickness (Figure 7.37) but also greater heartwood proportion (Figure 7.38)
- no difference in shrinkage (Muneri et al. 2003, 34-year-old *E. pilularis*)
- increase in total and *Select* grade board recovery with an increase in thinning intensity to a final stand stocking of 250 stems per hectare, but reducing with an increase in thinning intensity to stand stocking greater than 250 stems per hectare (Figure 7.39) - may only apply to unpruned stands.

Figure 7.29. The distribution of leaf area (m²/tree) and range of specific leaf area (m²/kg) for the upper, middle and lower parts of the crown of thinned (a and b) and unthinned (c and d) trees. Charts (a) and (c) show the northern aspect of the crown, charts (b) and (d) show the southern aspect. Figure and caption reproduced from Medhurst and Beadle (2000) - Figure 2

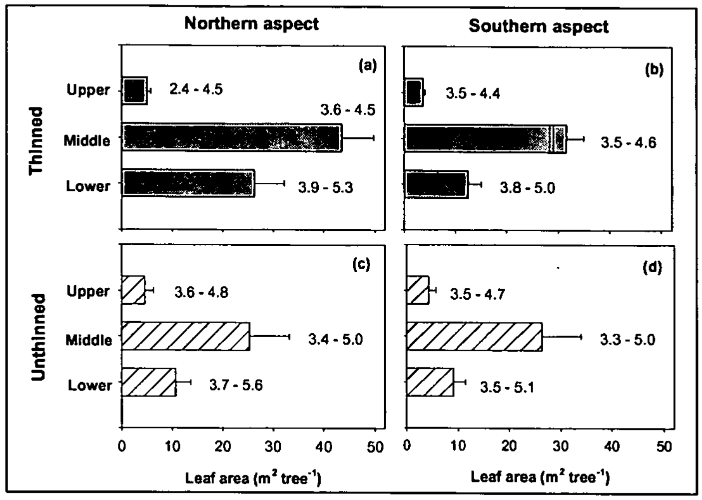


Figure 7.30. Mean instantaneous photosynthetic rates (µmol/m²/s) for old, mature and young foliage in the lower, middle and upper thirds of thinned and unthinned trees at Dover, October 1998. Asterisks indicate a significantly higher rate of photosynthesis when compared with foliage of the same age and crown position in the control. The white portions of each pie chart show the relative amounts of direct sunlight reaching the upper, middle and lower sections of each crown during the growing season. Figure and caption reproduced from Medhurst and Beadle (2000) - Figure 3

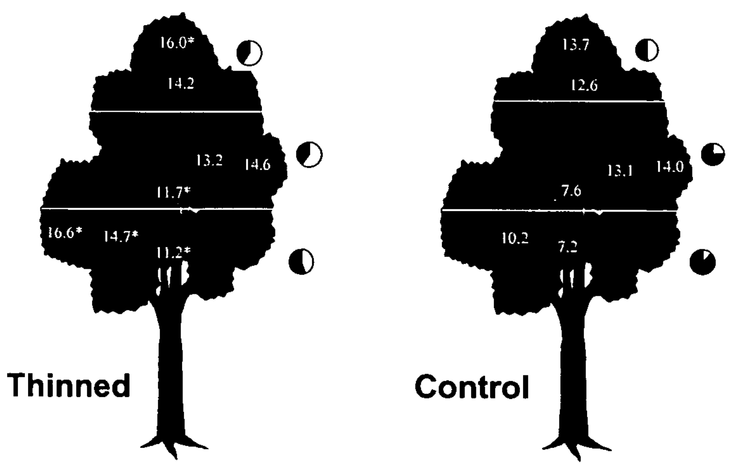


Figure 7.31. Efficiency of wood produced per unit of leaf area index (LAI) for 11 sites in Brazil for *E. grandis x urophylla* hybrids. Figure reproduced from presentation by Binkley and Stape (2004)

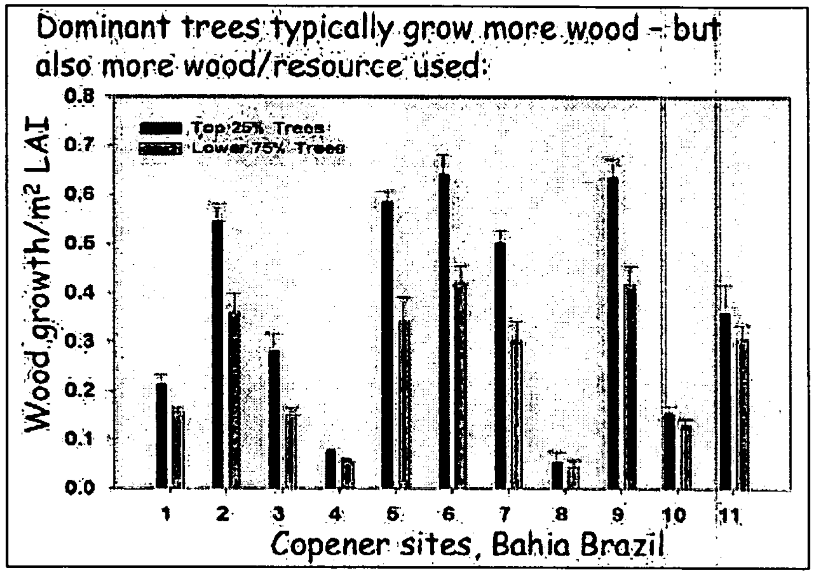


Figure 7.32. 37-year-old *E. pilularis* - basal area with age and initial stocking (S*) and thinning (T***) treatment. Figure reproduced from Muneri et al. 2003, Figure 2**

Basal area is total per-hectare stem cross-sectional area at a height of 1.3 m

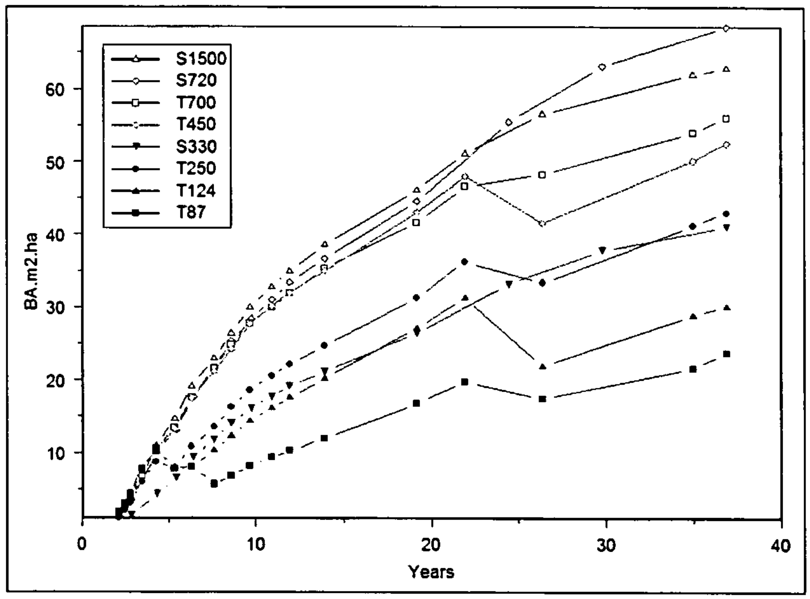


Figure 7.33. Thinning response in an *E. nitens* non-commercial thinning trial at St. Helens, Tasmania. The stand was non-commercially thinned at age 6 years. Response lines represent best 200 trees/ha. Initial establishment stocking 900 sph. Figure and caption reproduced from Medhurst and Beadle (2000) - Figure 1

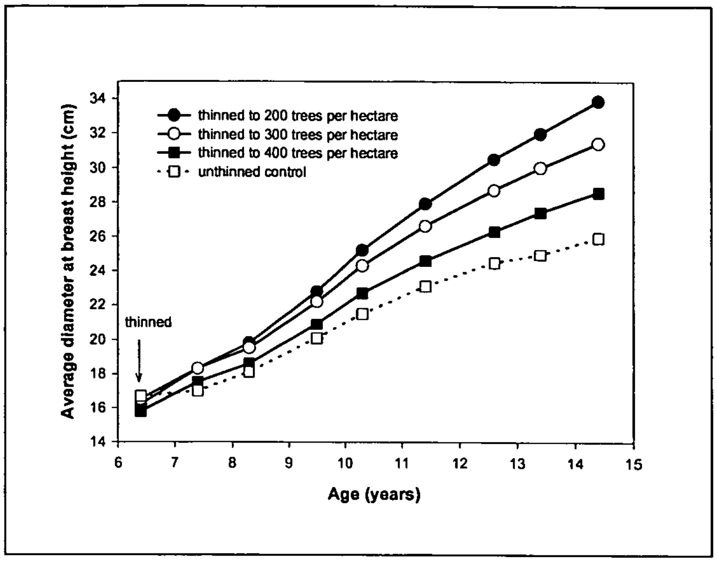


Figure 7.34. Thinning intensity and butt taper (mm / m) in 37-year-old *E. pilularis* versus thinning intensity - S1500 is the control (unthinned from 1500 sph), Txx represents the final stocking of xx sph after multiple thinnings. Data reported by Muneri et al. 2003, Table 7 - units not reported

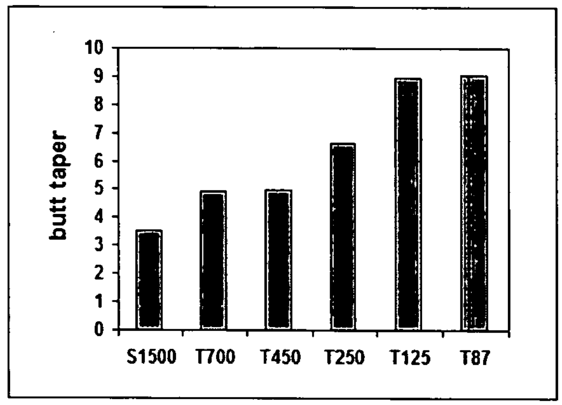


Figure 7.35. *E. grandis*, 12.5-years-old: average tree diameter, longitudinal growth strain, and basic density with silvicultural treatment (after data reported by Wilkins and Kitahara 1991)

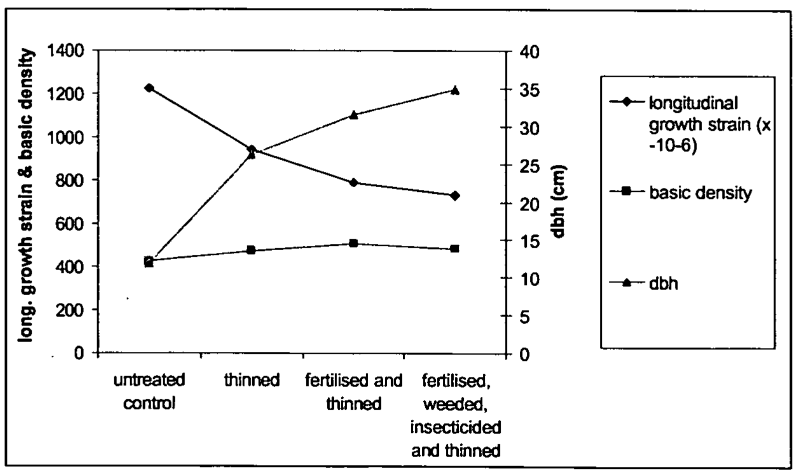
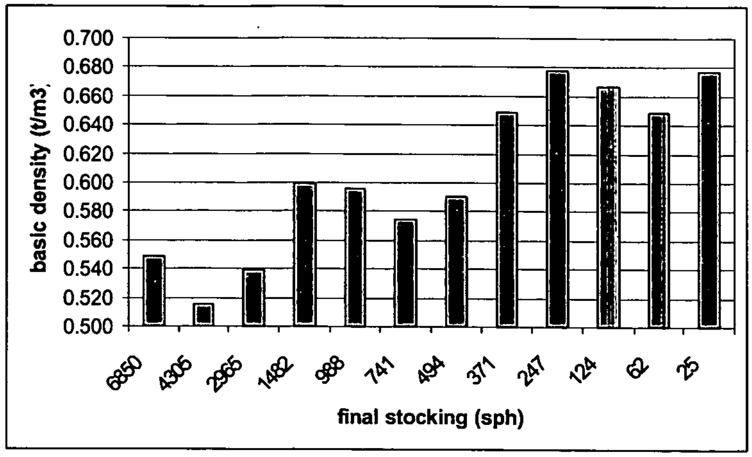
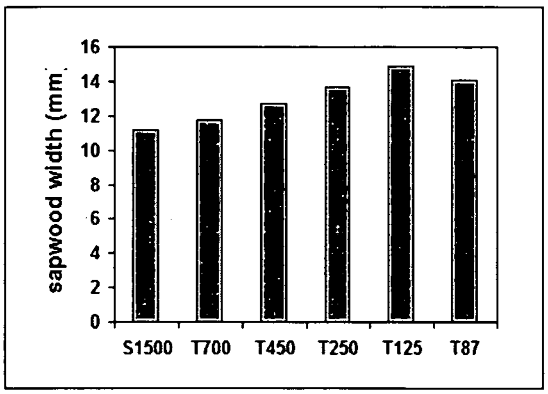


Figure 7.36. Basic density versus final stocking in 33-year-old *E. grandis* in South Africa (Malan and Hoon 1992) - All treatments established at 6,850 stems per hectare, multiple thinning operations





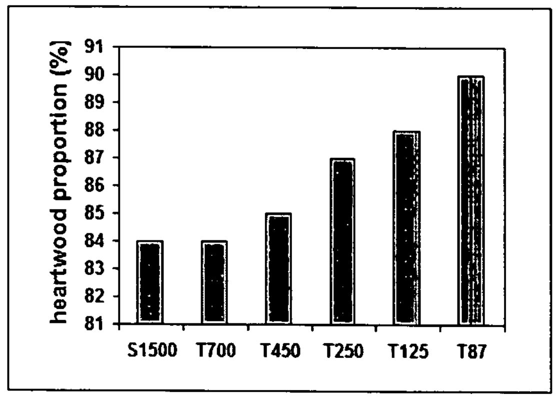
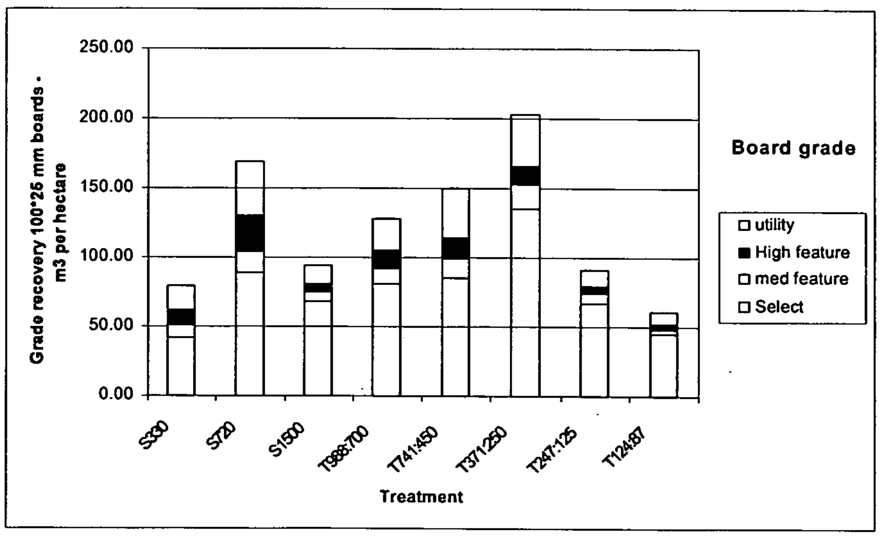


Figure 7.37. and 7.38. Sapwood width and heartwood proportion. Data reported by Muneri et al. 2003, Table 7

Figure 7.39. Sawn-board volume by board grade for 36-year-old *E. pilularis* by initial-stocking (S*) and thinning (T***) treatment. Figure reproduced from Muneri et al. (2003), Figure 10**



The timing of thinning may be a critical factor. Later heavy thinning (age 8 years from 1,100 to 220 sph) has been observed to be associated with increased tension-wood in retained stems in *E. globulus* (Figure 7.40), although application of fertiliser after later thinning may reduce the severity of tension-wood development (Figure 7.40).

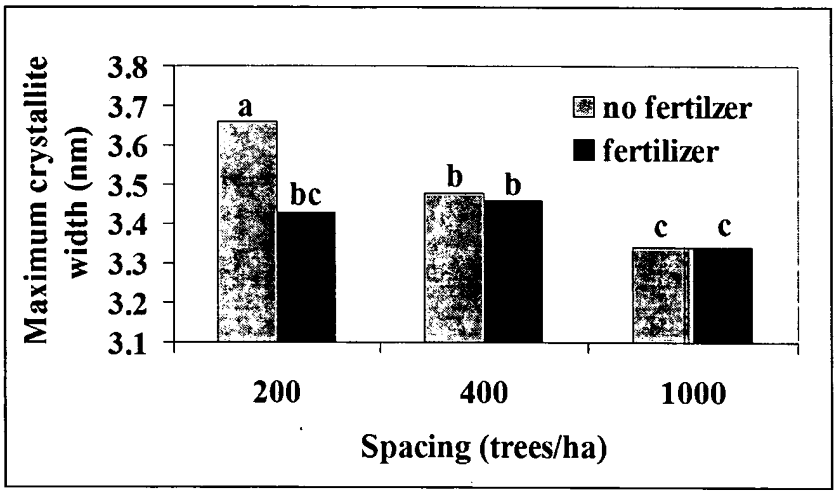
Conversely, in *E. globulus* stands where early thinning has been undertaken the difficulties of tension-wood are minimized (Washusen 2002, Washusen et al. 2004). A major aim of plantation development for solid-wood products should be in the reduction of tension-wood severity and within stem tension-wood volumes.

Waugh (2004) reported later thinned *E. globulus* (thinned at 10, harvest at 14) had almost 50% of sawn boards showing excessive spring or bow, compared to around 5% for 12-year-old trees thinned from an early age (Figure 7.41).

Nutto and Touza (2004) conclude that bigger trees have bigger crowns (Figure 7.42) and the key to maximising production of high-value large-diameter logs is to thin to maintain sufficient space between trees that will minimise inter-crown competition (Figure 7.43).

Figure 7.40. Maximum cellulose crystallite width for the spacing and fertilizer treatments in 13-year-old *E. globulus* thinned at age 8. Crystallite width greater than 3.4 nm indicates severe tension wood. (From Washusen et al. 2004)

Higher cellulose crystallite width is related to higher sawn-board warp in *E. globulus* (Figs. 5.2 and 5.3)



'a' is significantly different to 'b', 'bc' and 'c'; 'b' is significantly different to 'c'; and 'bc' is not significantly different from 'b' or 'c' at $p<0.05$.

Figure 7.41. Fraction of sawn boards showing excessive warp by log-source - *E. globulus*. Figure reproduced from presentation by Waugh (2004)

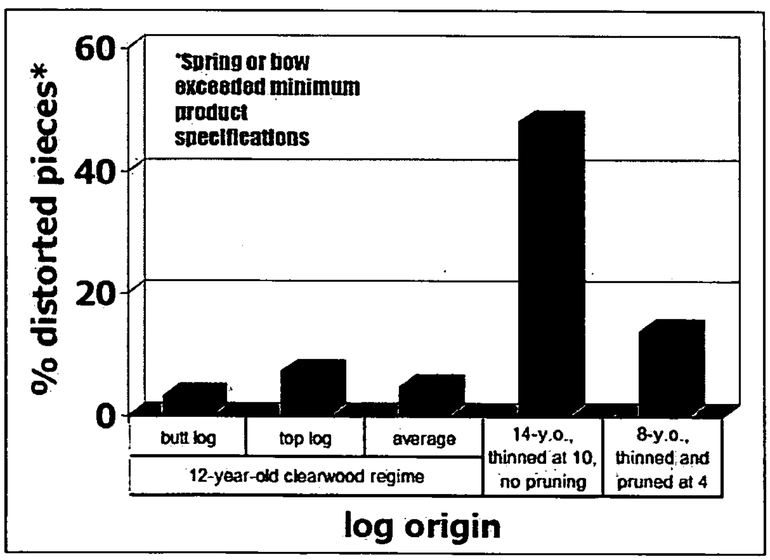
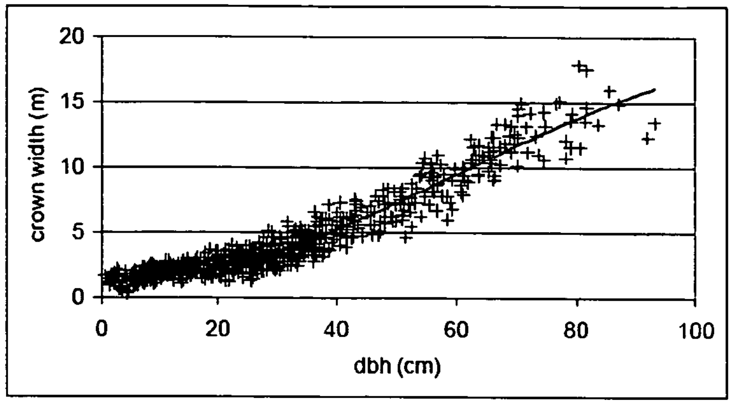
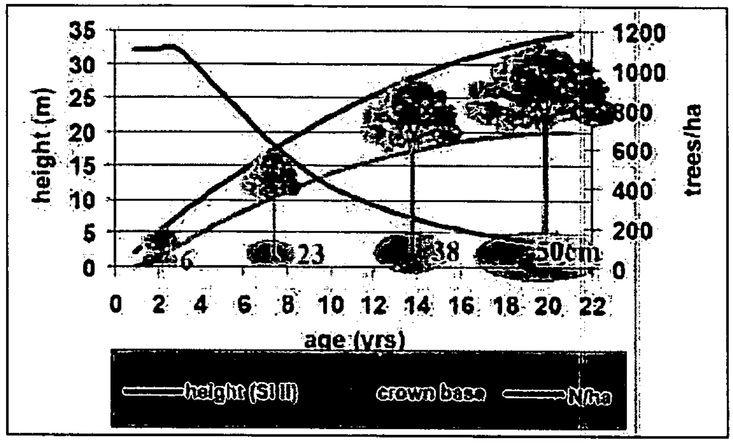


Figure 7.42. Relation between crown width and dbh in *E. globulus* grown in Galicia, Spain. Figure and caption reproduced from Nutto and Touza (2004), Figure 2	
Figure 7.43. Figure reproduced from presentation by Leif Nutto (Nutto and Touza 2004) - blue numbers indicate average tree diameter	

Muneri et al. (2003) concluded that heavy early thinning might result in lower log value due to a greater proportion of branch related defects, and that a high initial stand density promotes higher log value for lower log diameters (Figure 7.44). This may only be applicable for unpruned stands where branch size can be manipulated with stand density.

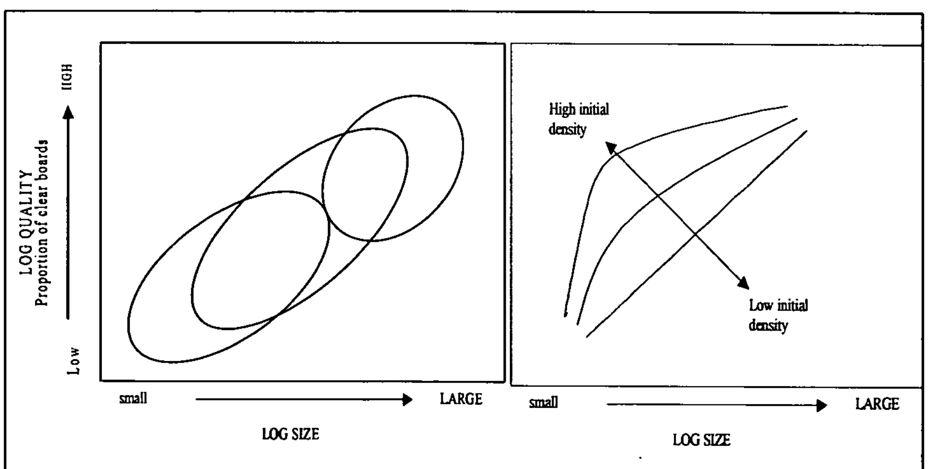


Figure 7.44. Diagrammatic representation of the effect of thinning and initial stocking on log quality. Increases in log quality due to thinning are largely related to increased log size. High initial densities appear to increase quality by reducing knot related defects. Figure and caption reproduced from Muneri et al. (2003), Figure 13

7.7.4. Pruning

The objective of pruning is to maximise the amount of clear wood produced by a tree (Montagu et al. 2003a). If branches are properly pruned whilst green there is a high probability that new wood will grow over the pruned branch stubs and that from then on knot-free clear wood will be grown on the stem. Montagu et al. (2003a) describe the diameter of the knotty core grown before pruning as the diameter over [branch] stubs (DOS) and the diameter of the new wood formed to cover the pruned branches as the diameter over occlusion (DOO), with knot-free clear wood formed outside DOO (Figure 7.45).

- Branches must be pruned whilst green (alive) and before canopy lift commences. To ensure that this is the case, stands scheduled for pruning must be managed to ensure that live branches are retained in the lower canopy until the stem reaches a suitable dbh for first pruning. This will depend on a combination of growth rate and tree age (Chris Beadle 2004, pers. comm.). Lower stocking results in slower green crown lift (Figure 7.18).
- In the absence of pruning lower branches will progressively die and be shed, be retained, or be drawn out (e.g. Figure 7.46). With *E. globulus* (for example) dead branches may be retained on the lower stem such that 40m tall trees may still have dead branches in the lower 3 m of stem (Figures 7.47 and 7.48) - Figure 7.49 depicts height to lowest dead and green branches with age, for three species of un-thinned eucalypt plantation in Tasmania and Victoria.
- Unpruned trees may have lower stems that look sawlog-suitable but they will usually contain significant knotty core (Figure 7.50).
- Pruning to a height that maintains at least 50% of the green canopy will not significantly reduce tree growth (Figure 7.51).
- If dead branches are pruned the branch stubs may be drawn out by the growing wood leaving resin/kino channels (Figure 7.52).
- Pruned branch stubs are subject to entry of wood decay fungi, with a probability of wood decay outbreak dependent upon site (Figure 7.53), branch size (Figure 7.54), wounding, and the post-prune application of sealants or fungicide (Figure 7.53).
- Subsequent pruning should occur before the lower retained crown dies, and again prune to a height that retains at least 50% of the green crown.
- In Australia pruning to 2.1 m at age 2 years, 4.2 m at age 4 years, and 6.4 m at age 5 years may be a suitable regime on sites with an MAI_{10} of 22 m^3/ha/year.
- The number of pruning lifts undertaken and the pruned height achieved is dependent upon the cost of pruning (which becomes more expensive with greater height) and the value of upper-stem pruned logs - in Chile some small growers are pruning to ten metres in five lifts.
- A difficulty in operational pruning is that variation between trees within a stand means that some trees will require pruning before others, and that operationally some will be pruned late whilst others will be pruned early (Figure 7.55).
- Pruned logs produce a higher proportion of *Select* grade sawn-timber than unpruned logs (Figures 7.56 and 7.57).
- There are species differences in the propensity to self-prune - Figure 7.49 shows a trend that *E. regnans* sheds branches to a greater extent than *E. globulus*, and that *E. nitens* has the lowest branch shedding of the three species presented. *E. grandis* is considered to be a species with a self-pruning habit, however, for relatively short rotations (around 20 years) core diameter will only be effectively minimised with managed pruning from an early age (Shield 2004). In terms of

fast-grown plantation eucalypts for solid wood, 'self-pruning habit' should be interpreted as 'may shed some branches, but pruning still required'.

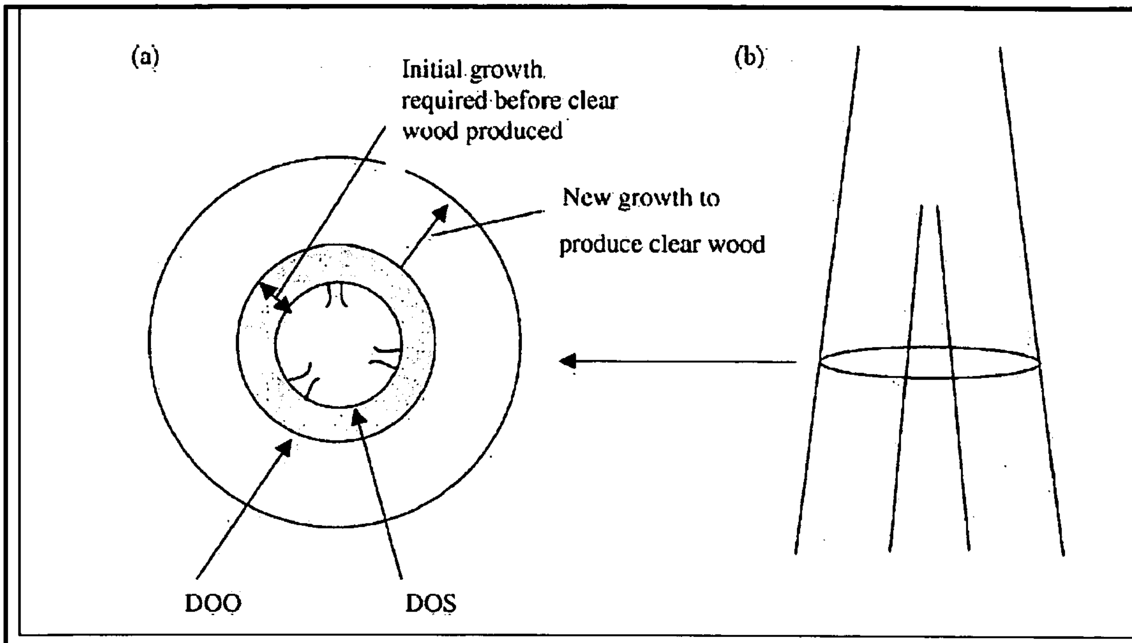


Figure 7.45. (a) The stem cross-section highlighting the defect knotty core. The knotty core is a product of the diameter over-pruned branch stubs (DOS); plus the additional growth before clear wood is produced to give the DOO, and (b) the tapering characteristic of the knotty core within the tree. Figure and caption reproduced from Montagu et al. (2003a), Figure 2

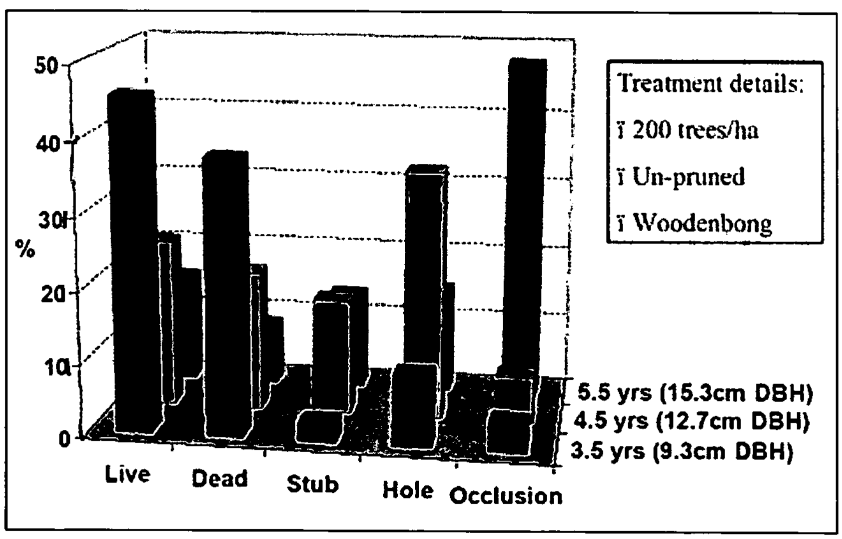


Figure 7.46. (*Corymbia spp.)* Glass Log measurement technique; Morphology of individual branches recorded over numerous years; Branch status (ages 3.5 - 5.5 years) - (Figure and caption reproduced from Geoff Dickinson presentation- QDPI CD)

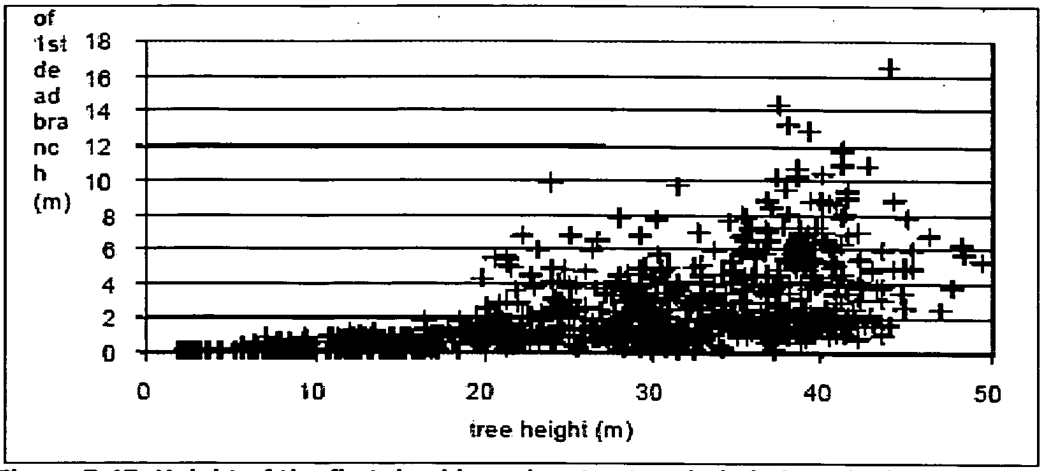


Figure 7.47. Height of the first dead branch not yet occluded plotted with total tree height. Only when the eucalypts reach a total height of more than 20 m a clear bowl can be found at a few individual trees. Figure and caption reproduced from Nutto and Touza (2004), Figure 4

Figure 7.48. Estimated crown base recession for sawlog production. In order to avoid pruning dead branches, first interventions should be made at ages between 2 and 3 years. Figure and caption reproduced from Nutto and Touza (2004), Figure 5

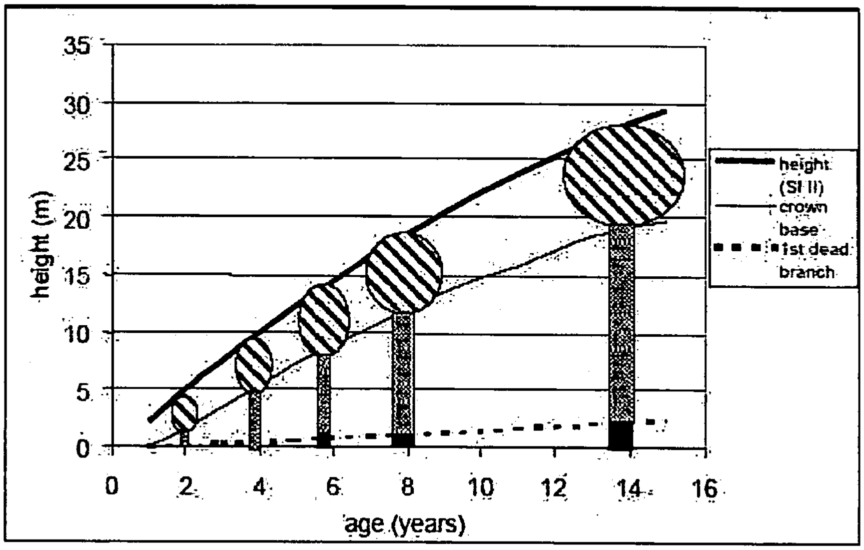


Figure 7.49. Height of green and dead branches with age in fibre-managed crops of *E. globulus*, *E. nitens* and *E. regnans*. Data reproduced from Yang and Waugh (1996a and 1996b)

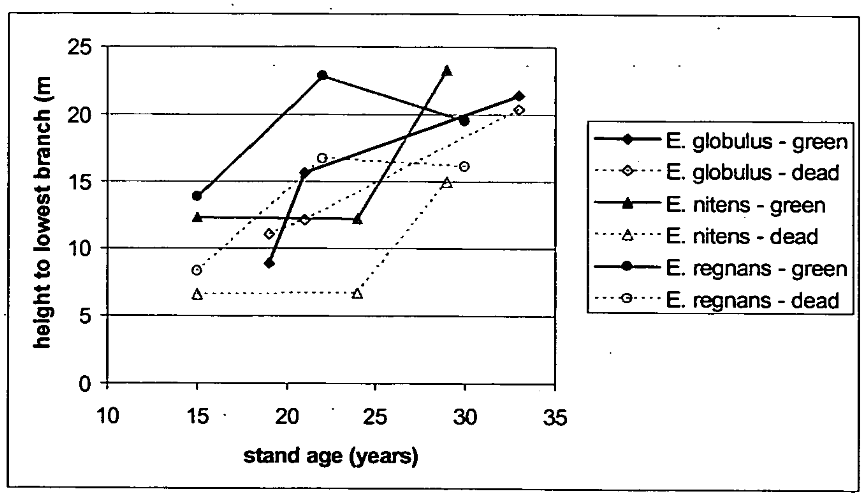


Figure 7.50. Branch defect in *E. globulus* sawlog sourced from a mature unpruned stand of *E. globulus* in Galicia, Spain (Photograph Bruce Greaves 2004)

Figure 7.51. Diameter increment after pruning, by level of crown removal. Figure by Chris Beadle, after results reported in Pinkard and Beadle (1998)

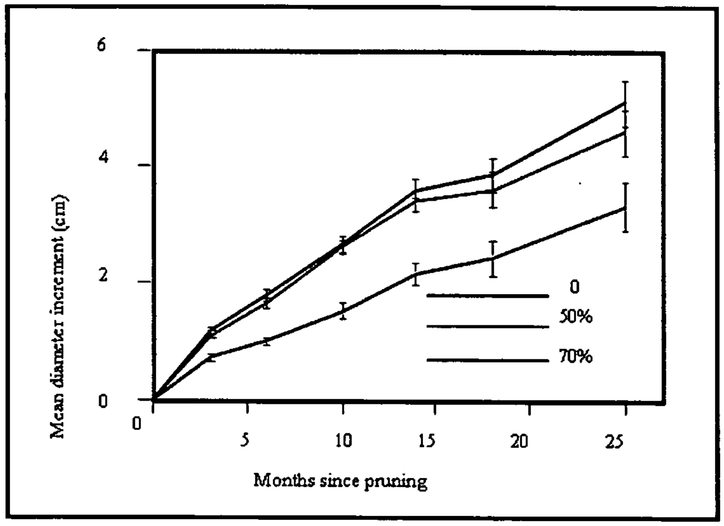
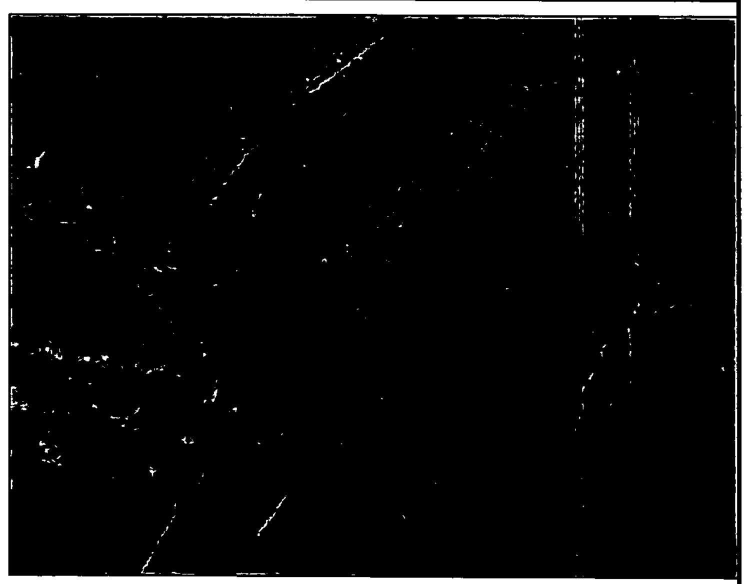


Figure 7.52. Potential problem with pruning dead branches: resin-tract left by branch stub as stub is drawn out by growing tree (Carolyn Mohammed pers. comm.). Disk taken from 1.3 m height from an unpruned stand of 15-year-old *E. globulus* growing Ridgley, NW Tasmania (Photograph Bruce Greaves)

Note that the discoloration (on right) is a decay track resulting from extraction of a wood-sample core at an earlier-age



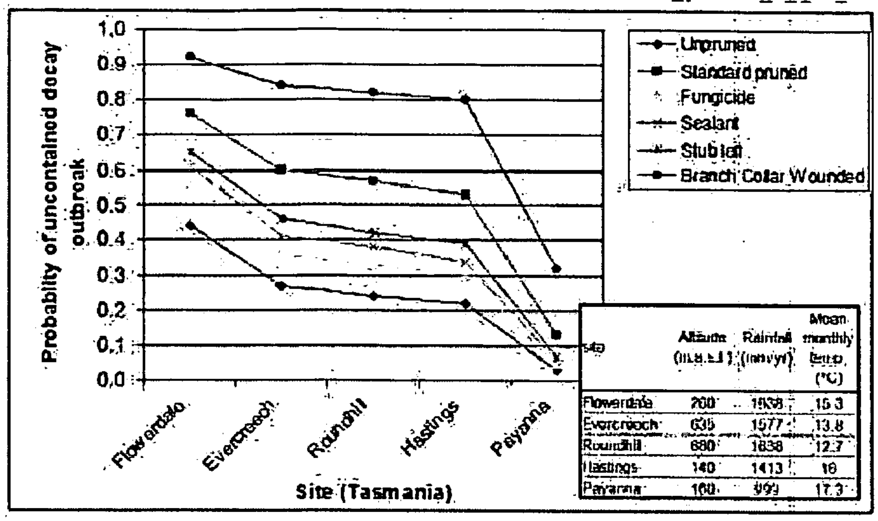
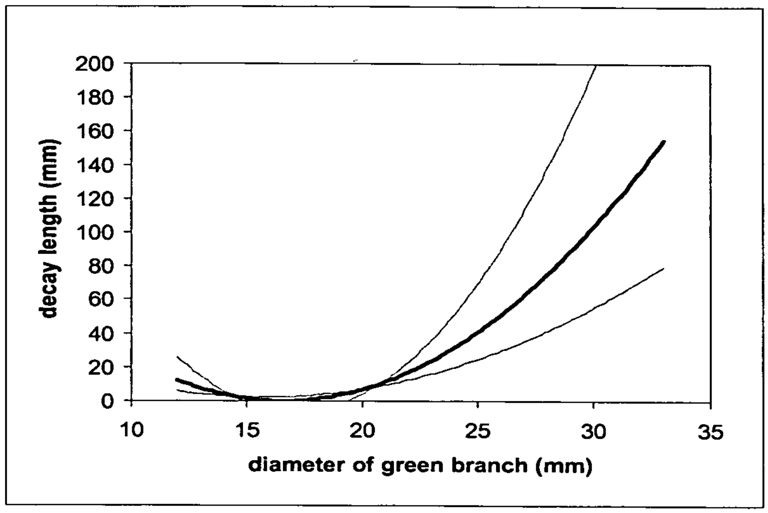


Figure 7.54. *E. nitens*, age 4 years, Flowerdale - Tasmania, one year after pruning: predicted decay outbreak length as influenced by the branch diameter of a green branch. Figure and caption reproduced from Mohammed et al. (2000) - Figure 2



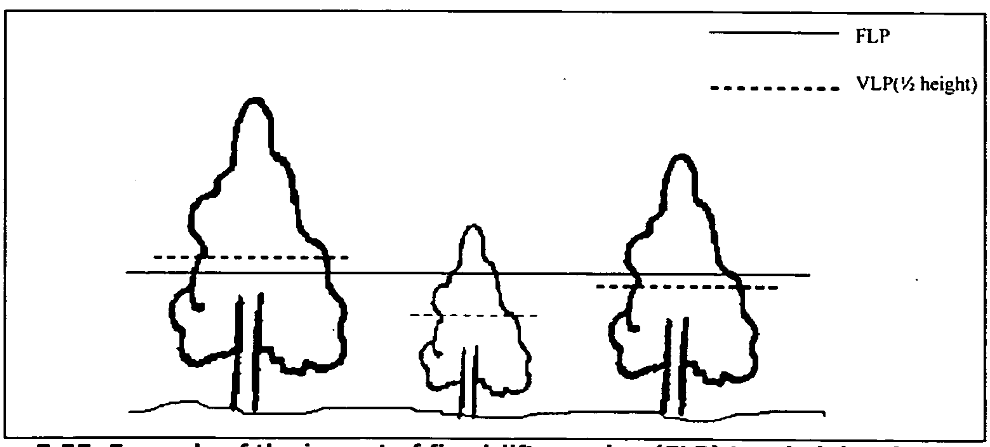
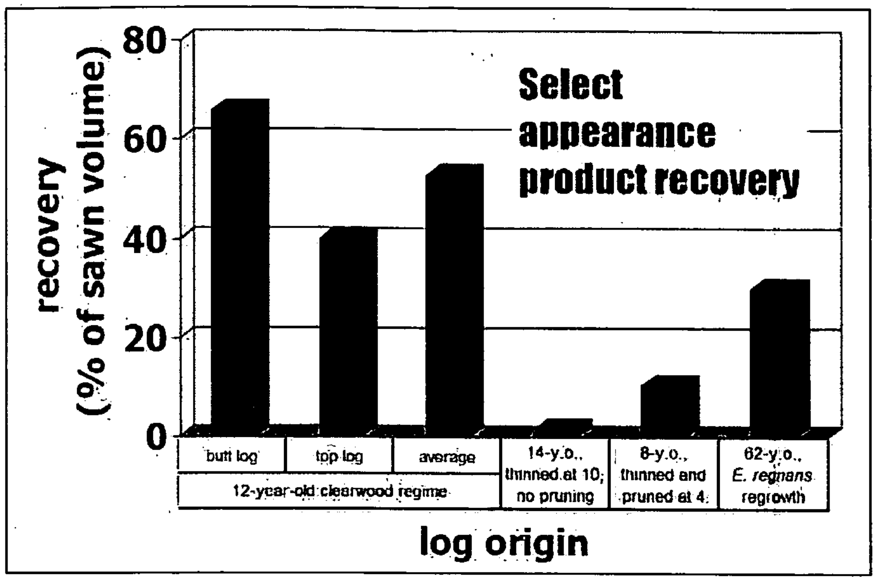


Figure 7.55. Example of the impact of fixed-lift-pruning (FLP) to a height of 2.0 m, and variable-lift-pruning (VLP) to half tree height, on the diameter over-pruned branch stubs and amount of crown removed following pruning. Figure and caption reproduced from Montagu et al. 2003a, Figure 3

Figure 7.56. Recovery of *Select* appearance product (of total sawn volume) by log-source - *E. globulus*. Figure reproduced from presentation by Waugh (2004)



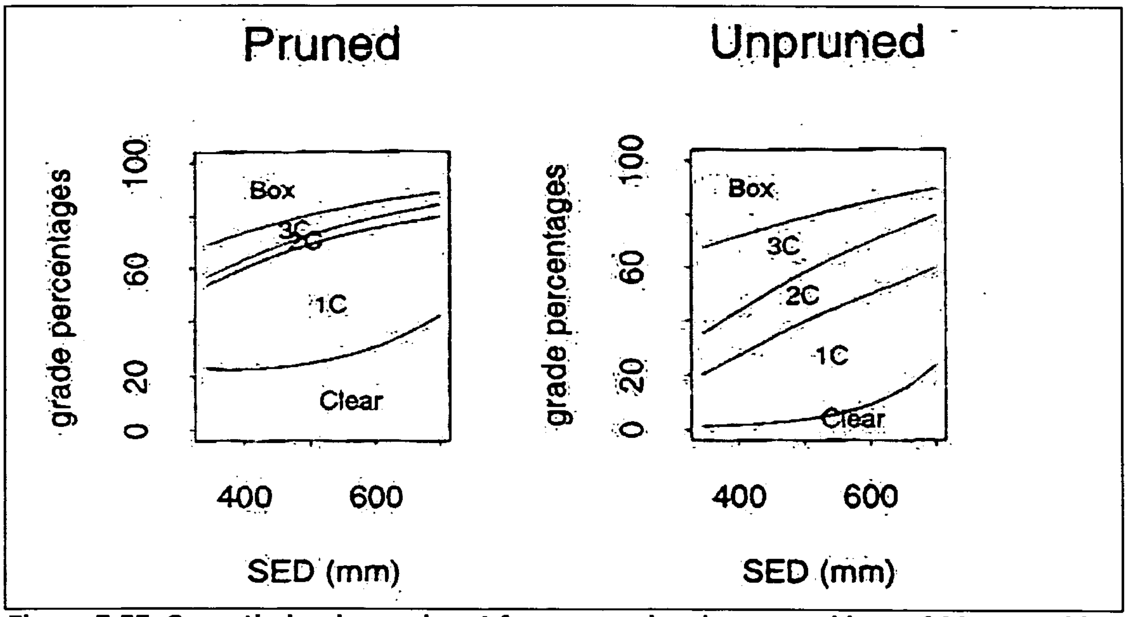


Figure 7.57. Sawn timber by grade cut from pruned and unpruned logs of 29-year-old *E. fastigata*. Grade recovery as a percentage of timber volume per log, ignoring kino, by log SED. Figure and caption (in-part) reproduced from McKenzie et al. (2000)

7.7.5. Resistance to pathogens

Growing plantations in monoculture stands is believed to increase the risk of an outbreak of pests and diseases of the stand which can reduce stand productivity, or render the grown wood unsuitable for high value utilisation (for example the canker causing pathogen *Coniothyrium* in South Africa and parts of South America - Figure 7.58, and the bark-boring *Phoracantha* in southern Spain - Figure 7.59).

Growing eucalyptus species as exotics can benefit from as-yet-unintroduced pests and diseases. The productivity advantage associated with an absence of eucalyptus-tolerant pathogens in southern Chile may be 10 to 15% (unconfirmed local estimate).

Pest control can be expensive and can be greater than the value of volume loss associated with a pathogen infestation.

Breeding for pest resistance seems possible with moderate heritabilities for pathogen resistance reported for forest tree species. The longevity of pathogen resistance achieved through breeding is uncertain as pathogens may adapt relatively quickly when confronted with a stand of 'resistant' trees. However, deployment of *Phoracantha* resistant clones of *E. globulus* by ENCE in southern Spain appears to have contributed significantly to the control of the insect (other measures include introduction of a parasitic wasp).

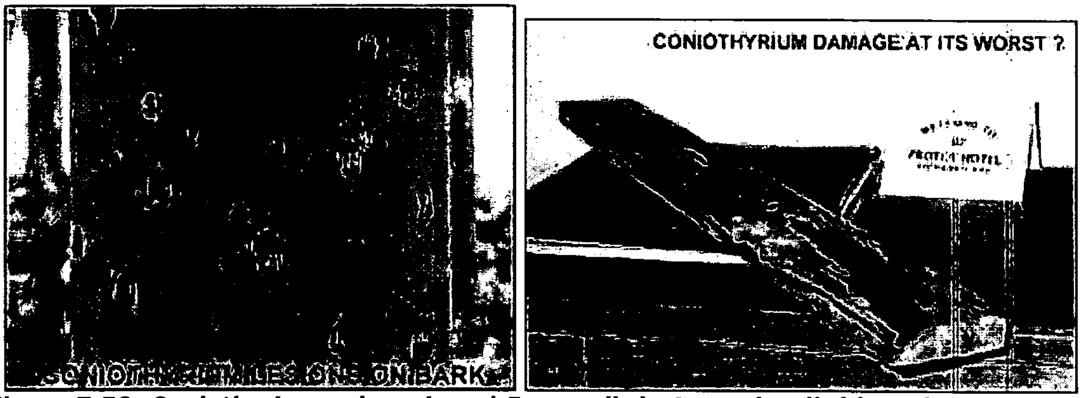
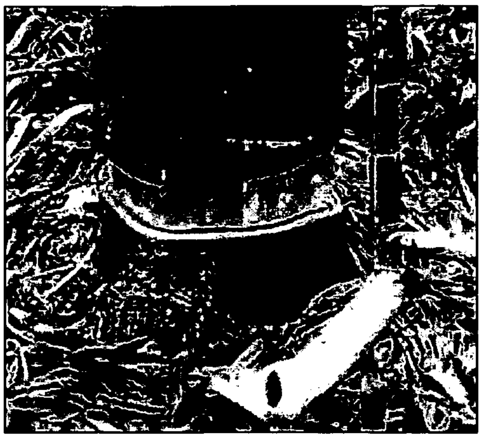


Figure 7.58. *Coniothyrium zuluensis* and *E. grandis* in Argentina (left), and South Africa (right). Images reproduced from Shield (2004) presentation

Figure 7.59. Stem damage/defects in *E. globulus* resulting from *Phoracantha* infestation - southern Spain. Photograph Bruce Greaves

7.7.7. Reducing growth stress in standing trees

An experiment undertaken in Chile (Mohring and Dunn 2004) demonstrated both pre-harvest girdling and pre-harvest biocide injection (Figure 7.60) increased green-off-saw recovery of sawn timber by 15-20% compared to the untreated control, except for larger logs (30-35 cm) where the effect was minimal. Both treatments increased recovery of peeled veneer over untreated control. It was suggested that the advantage gained from pre-harvest treatment increased with time before harvest to a maximum at treatment four months pre-harvest.



a: Girdling

a: Biocide injection

Figure 7.60. Experimental treatments to reduce growth stress in standing trees prior to final harvest *E. nitens*, Chile. Photograph reproduced from Mohring and Dunn 2004

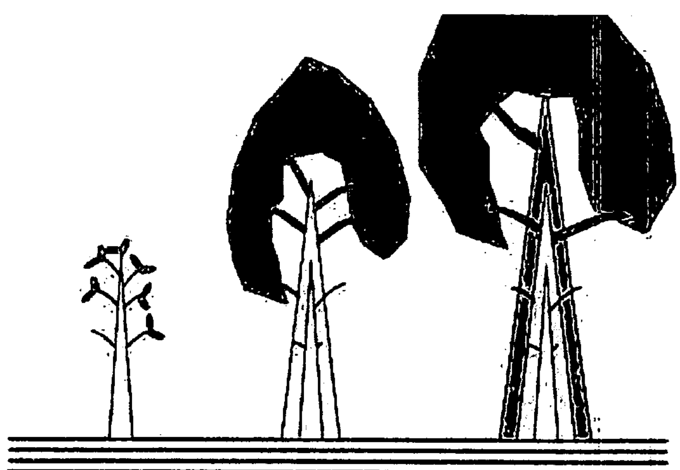
7.8. Variation within-tree

A tree grows by depositing a new layer of wood, under the bark, on the outside of the previous year's deposited wood (Figure 7.61). The wood that is deposited in a year's growth is different from the wood deposited in the previous year's growth, up until the tree reaches 20 to 40 years old, after which time the deposited wood is relatively consistent year-to-year (Figure 7.62).

Twenty-five-year-old trees show more variation from pith-to-bark (wood properties vary radially through the majority of the stem) than 110-year-old trees (most variation is in the core of the tree) (Figure 7.63).

Juvenile wood can be defined as the wood deposited when the tree is young that has properties that are of 'unacceptably' low quality (the definition of acceptability varies with the utilisation process). Figure 7.64 depicts variation in juvenile wood core diameter in *Pinus radiata* and its influence on the recovery of juvenile-wood-free sawn-timber.

Figure 7.61. Generalised depiction of tree growth: a tree grows by depositing a new layer of wood, under the bark, on the outside of the previous year's deposited wood



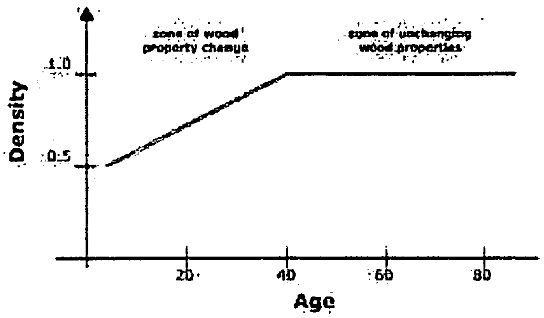


Figure 7.62. Generalised pith-to-bark variation in average basic density

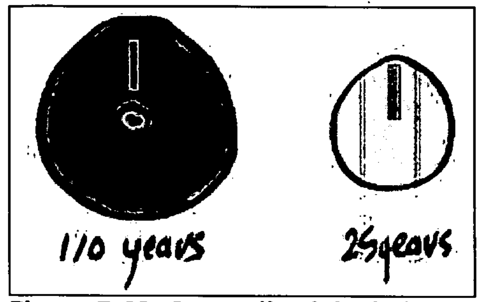
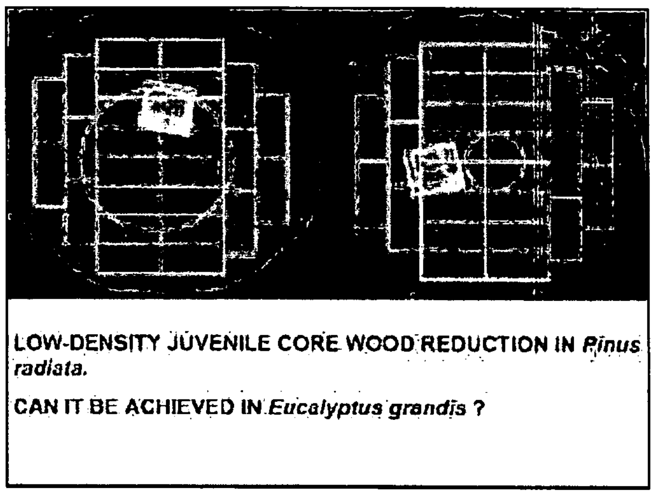


Figure 7.63. Generalised depiction of zone of wood property change (yellow) and zone of unchanging wood properties (brown) in 110-year-old natural-stand log and 25-year-old plantation-grown log, and the location of a quarter sawn board

Figure 7.64. The diameter of the juvenile wood core in fast-grown trees is seen to be <u>the</u> priority area for research into wood quality. Figure and caption reproduced from presentation by Shield (2004)



Density increases from pith to bark, and from the base of the stem to the top (Figure 7.65). MOE increases from pith to bark (Figure 7.66).

Figure 7.65. *E. globulus* density profile (at 12% moisture content) from pith to bark measured at the trees of age 25 at 4 different heights: 1.30 m (den 1.3), 25 and 50% (den 25 and den 50) of total tree height and 1 m below crown base (den 1cb) - Galicia, Spain. Figure and caption reproduced from Nutto and Touza (2004), Figure 7

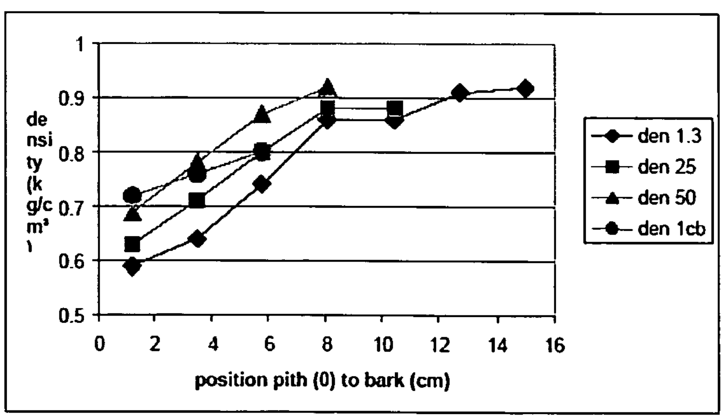
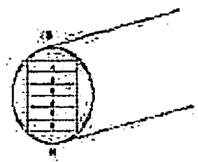
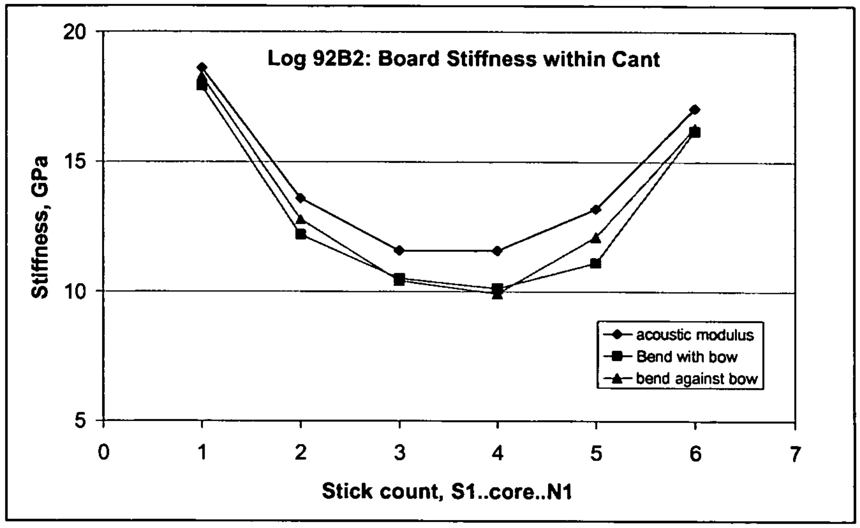


Figure 7.66. Comparison of acoustic modulus with that obtained by 3-pt bend - *E. pilularis* - 36 y.o. Figure and caption reproduced from Muneri et al. (2003), Appendix B, Figure 6



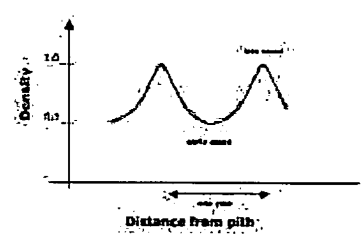


Other wood properties which vary from pith to bark are:

- late-wood fraction may increase from pith to bark (which may explain some of the observed increase in basic density from pith to bark)
- fibre length increases
- microfibril angle
- cellulose crystallite width.

The wood deposited in a year's growth shows considerable variation in many fibre-related characteristics between the earlywood (deposited in spring) and latewood (deposited in summer): for example, basic density (Figure 7.67).

Figure 7.67. Within-year variation in basic density



7.9. Growing high value logs in eucalypt plantations

7.9.1. Estimating log grade production by silvicultural regime

Growing high value logs in eucalypt plantations for sawing or peeling requires stand density to be reduced and branches to be pruned relatively early in the rotation. There seems to be little argument that early reduction of stocking to around 200 stems per hectare is appropriate for the production of large diameter logs.

There are three significant strategies for spacing to produce large diameter logs (suitable for sites with MAI_{10} of around 22 m^3/ha/year - optimal operations move in time with higher or lower growth). The estimated log production with time by log-grade for each are depicted below along with estimated log production for low value management (fibre crop - Figure 7.68):

- establish at 1,100 stems per hectare, thin non-commercially to 600 sph at age 3 years and to 200 sph at age 4 years (Figure 7.69)
- establish at 1,100 stems per hectare, thin commercially to 200 sph at age 9 years to recover 110 m^3/ha of pulpwood (Figure 7.70 including pruning, Figure 7.71 without pruning)
- establish at 500 stems per hectare, thin non-commercially to 200 sph at age 4 years (Figure 7.72).

Table 7.6 describes assumed log-grades used in the growth simulations.

Table 7.6. Assumed log grades used in FFT4 growth-model predictions of stand growth

log grade code	log grade	Diameter UB (cm)		Length (m)	
		minimum	maximum	minimum	maximum
S1_P	sawlog category 1, pruned	40	no max.	3.6	11
S3_P	sawlog category 3, pruned	35	no max.	3.6	11
S3UP	sawlog category 3, unpruned	35	no max.	2.9	11
SHUP	sawlog, unpruned, Hew Saw	24	35	3.5	11
Pulp	pulpwood	7	no max.	2.4	11
X	waste				

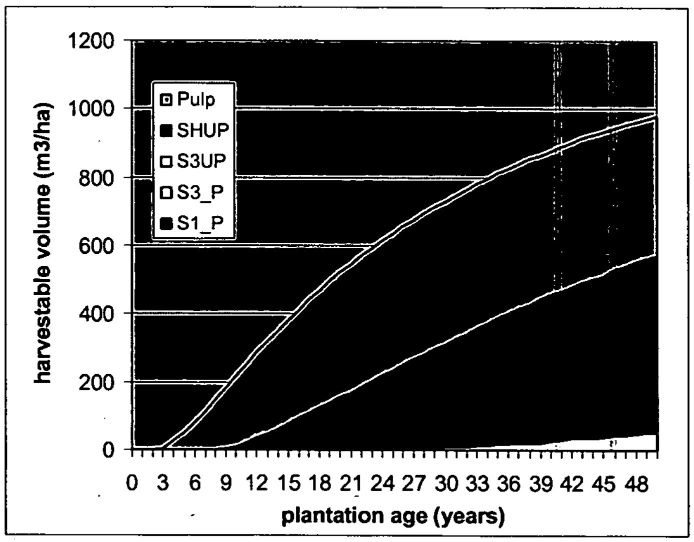
Description	**Log-grade distribution with stand age - log grades are described in Table 7.6. Estimates after Farm Forestry Toolbox growth model (V.4.9 with modifications)**
Figure 7.68. Low value fibre management: no thinning or pruning **Generates pulp logs and some unpruned sawlogs**	

Figure 7.69. High value management with pruning and early non-commercial thinning:

- Age 2: prune 350 sph to 2.1 m
- Age 3: thin to 600 sph, prune 250sph to 4.2 m
- Age 4: thin to 200 sph, prune to 6.4 m

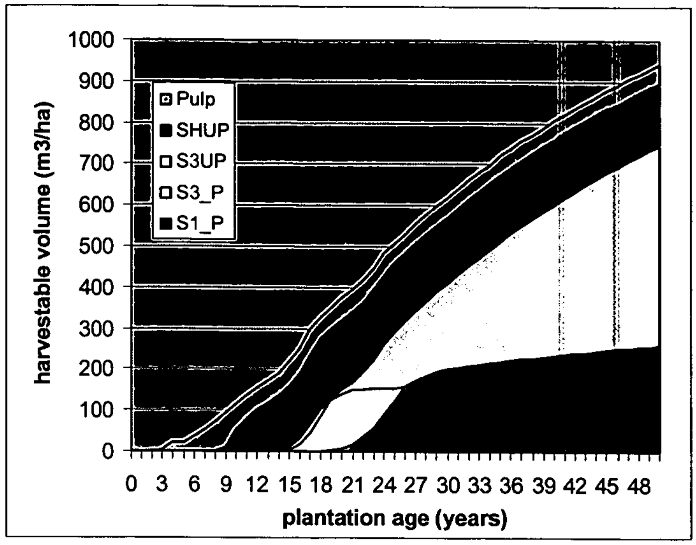


Figure 7.70. High value management with pruning and a commercial thin for fibre at age 9 years:

- Age 2: prune 350 sph to 2.1 m
- Age 4: prune 250 sph to 4.2 m
- Age 5: prune 200 sph to 6.4 m
- thin to 200 sph (111 m^3/ha fibre logs)

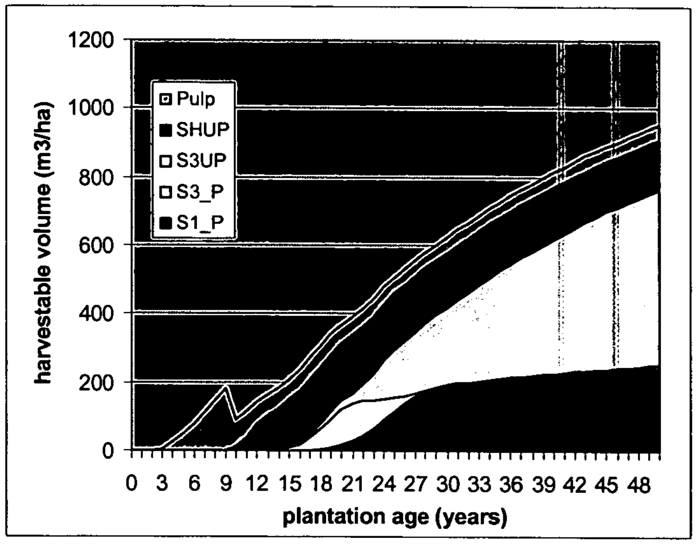


Figure 7.71. Medium value management with no pruning and commercial thinning:

- thin to 200 sph (111 m^3/ha fibre logs)

Generates no pruned logs

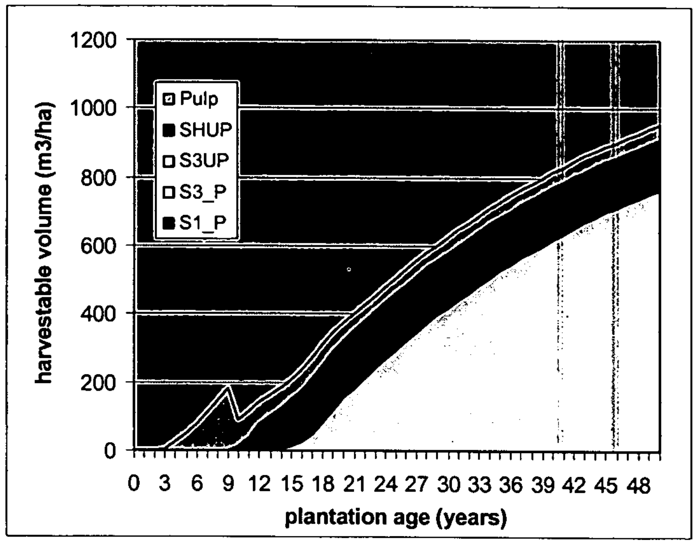
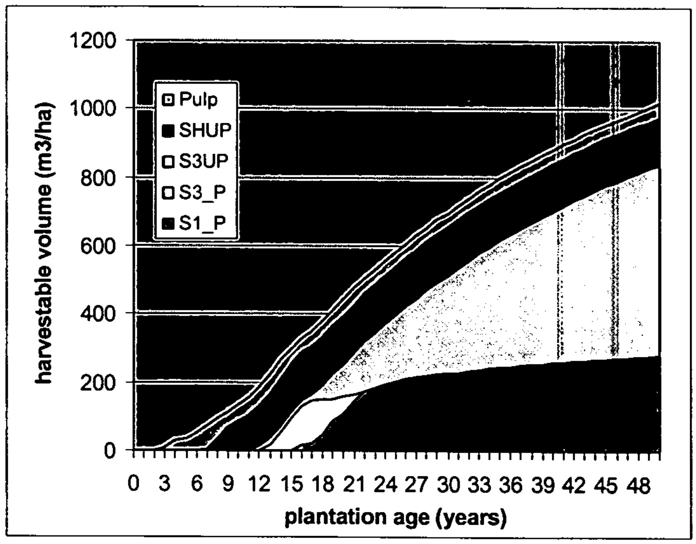


Figure 7.72. High value management with low establishment stocking (500 stems per hectare), pruning and early non-commercial thinning:

- Age 2: prune 350 sph to 2.1 m
- Age 4: thin to 200sph, prune to 4.2 m
- Age 4: prune to 6.4 m



7.9.2. High value silviculture elsewhere in the world

Variants of silviculture options for high value logs described above are used elsewhere in the world:

- In Uruguay, where growth rates are higher, thinning and pruning operations are undertaken earlier in inverse proportion with greater growth rate (Shield 2004). Pruning is of selected stems to a height of 10 m by age 5 years (Austin 2001).
- In southern Chile some owners of small forest areas (around 180 hectares of *E. nitens*) are undertaking five and six thinnings and four pruning operations to age 12 years with final harvest age unknown.
- In South Africa four thinning operations have been used to reduce the stocking in eucalypt plantations from 1333 trees/ha to 250 trees/ha (Medhurst and Beadle (2000) citing Schönau and Coetzee (1989)).

7.9.3. Multiple and overlapping crops

Possible refinements of sawlog silviculture include:

- In Galicia in northern Spain proposed silviculture for high value sawlogs in *E globulus* crops involves multiple pruning operations, and three commercial thinnings to age 16 years, with clearfall at age 26 years. A proposed alternative involves pruning and two commercial thinnings to age 10 years, then allowing coppice regeneration to grow a pulpwood stand under the canopy, with clearfall of both stand strata at age 26 years (Table 7.7 after Nutto and Touza 2004).
- Growing eucalyptus in a 50:50 mix with *Facaltaria* produced larger eucalypt stems and more total volume of eucalyptus at age 18-20 years than did growing a pure crop of eucalyptus (Figure 7.73 after Binkley 2004).

Table 7.7. Table reproduced from presentation by Leif Nutto (Nutto and Touza 2004)

	Sawlog				"Standard with Coppice"					Yield table pulp	
		Volumen (m³)				Volumen (m³)					Volumen
age	dbh	rem.	Thinn.	N/ha	dbh	rem.	Thinn.	under crown	N/ha	dbh	rem.
5	15,2	46,3	46,3	550	15,2	46,3	46,3	-	550	-	-
7	20,3	112,3	0	550	20,3	112,3	0	-	550	13,3	84
10	26,9	119,9	143,8	250	26,9	62,3	201,4	-	130	17,4	201
13	32,6	213,3	0,0	250	32,6	110,9	0	-	130	20,1	323
16	37,4	165,5	152,8	130	37,4	165,5	0	64,0	130	22,1	433
19	41,6	222,2	0	130	41,6	222,2	0	-	130	-	-
22	45,2	275,1	0	130	45,2	275,1	0	148,7	130	second rotation	
25	48,5	322,2	0	130	48,5	322,2	0	-	130	-	-
26	50,0	344,3	0	130	50,0	344,3	0	202,0	130	12,2	263
Vol.total		687,2				794,0					696
Vol.pulp		572,0				678,9					696
Vol.sawn		115,2				115,2					0

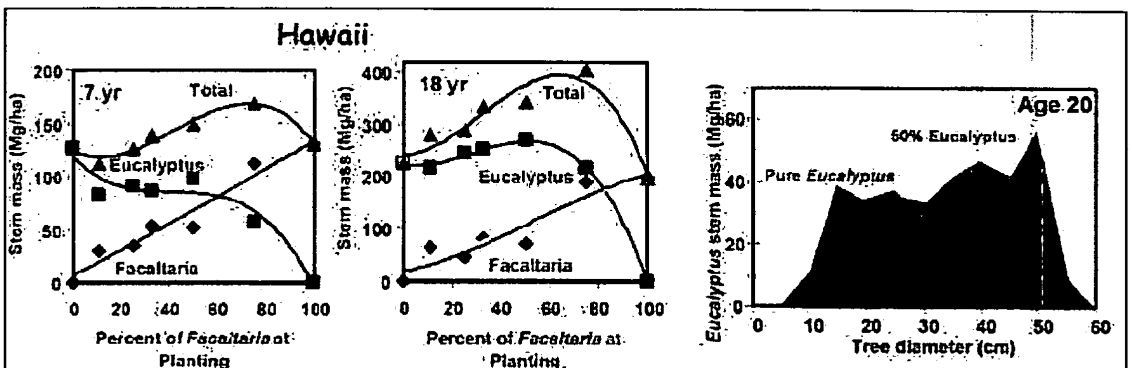


Figure 7.73. Stem biomass in eucalypt/*Facaltaria* mixed crop versus the crop mix, and stem size distributions for 50% and 100% eucalyptus crops at age 20 years. Figures reproduced from presentation by Binkley (2004)

7.10. The value of late management intervention

The bulk of eucalypt plantations grown in Australia and elsewhere in the world are managed for fibre - that is, established at relatively high stocking (1000-1600 stems per hectare) with little on going management intervention of significance. As described

above, trees grown for fibre grow small stems with generally regular small branches. As they grow to compete for light, they have a high ratio of height to stem diameter.

The keys to high value silviculture are early pruning to remove the branches whilst they are alive, and early thinning the number of trees on the site to encourage the stems to increase in diameter. But can fibre managed stands be 'converted' to higher-value stands with late management intervention?

Late pruning, once branches have died, may by pointless. A significant proportion of pruned branch stubs may not occlude but be drawn outwards by the growing stem leaving significant defect traces (Figure 7.52). This is reportedly common in both collapse prone southern species and in northern 'self pruning' species. As the base of the green crown can rise rapidly, achieving a height of around five metres by age 4 years (e.g. Figure 7.48), and leaving dead branches below, pruning after age 4 years will not result in certain development of clear wood below five metres. The logs can still be pruned about this height, but this increases pruning costs and presents operational difficulties later as the late pruned section will need to be identified and graded out of the high value product stream.

There is little doubt that unpruned stands will produce some good quality sawlogs with relatively few knot defects (Washusen and McCormick 2002, Washusen et al. 2004). However, the volume of sawlogs produced is likely to be much lower than where pruning has been conducted. Although this is likely to be species dependant, in some trials these yields are sufficiently low to cast doubt on plantations ever producing sufficient sawlogs to seriously supplement supply from natural forest sources.

Late thinning will generally result in a greater diameter increment on retained trees although some species on some sites will not respond to a late reduction in competition with an increase in growth sufficient to justify thinning. Rotation length will also be increased. In *E. globulus,* late thinning (age 8-10 years) has also been associated with increased occurrence of tension wood (Figure 7.38), and occurrence of excessive warp in sawn boards (Figure 5.2 and 5.3). Fertilising after later thinning may reduce the development of tension wood (Figure 7.38), and tension wood development following later thinning may be species and site dependent.

If higher-value markets for 'knotty' wood can be found, late intervention involving thinning may be worthwhile (Hingston 2002), providing post-thin tension wood development is not a significant problem.

7.11. Improvement

Improvement, both in silvicultural management and deployment of 'better' genetic stock (better species, better clones, better families), has significantly increased productivity (for example Figure 7.74 from the Amazon).

Binkley (2004) (citing Pallett and Sale 2004) presented sources of volume gain in eucalypt species grown in South Africa: genetic improvement accounted for 20% of volume gain and stocking and silviculture the other 80% (Figure 7.75).

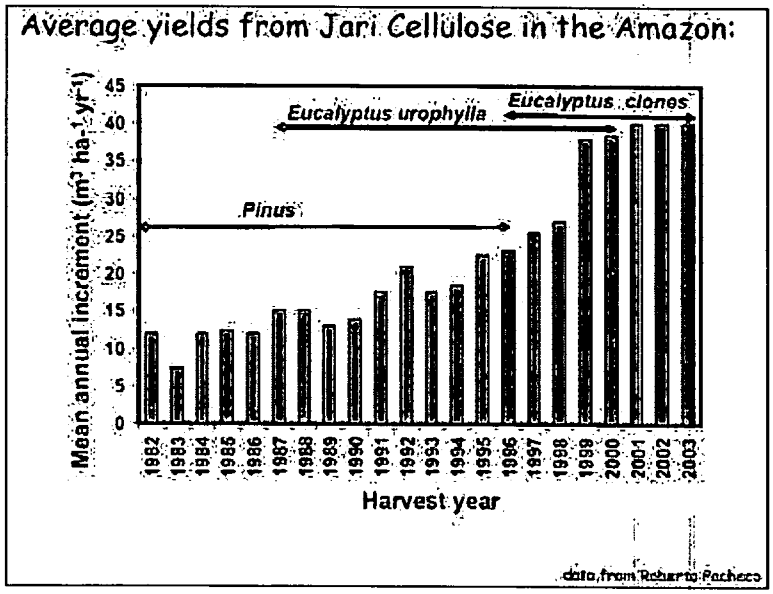


Figure 7.74. Demonstrating improvement: average yield per hectare with time. Figure reproduced from presentation by Binkley (2004)

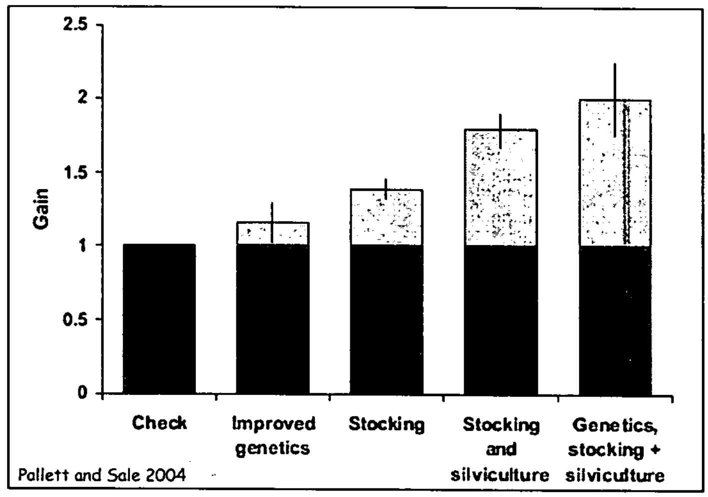


Figure 7.75. Sources of volume gain in eucalypt species in south Africa. Figure reproduced from presentation by Binkley (2004)

As discussed in section 7.2.3 above, gain from improvement can only be defined in terms of the objective for improvement, and the objective is not necessarily the maximisation of biomass production per unit of land area. Wood quality may be more critical for solid-wood utilisation systems than it is for pulpwood utilisation systems, and there remains a pressing need to quantify the relative importance of quality traits.

8.0. Economics

There are five basic conditions that must be met before industries can sustainably produce solid wood products from a plantation hardwood resource. These are:

- Timber users must demand and be willing to pay a suitable price for a locally produced fit-for-purpose product manufactured from the resource
- Timber producers must be able to manufacture (mill and recover) these products from the resource at a rate and cost that generates a sufficient return when they sell it to users, either in Australia or overseas
- Plantation growers must be able to grow enough of a resource suitable for these products at a cost that generates a sufficient return when they sell it to timber producers
- Financial institutions and economic infrastructure must exist that allows growers and producers to operate efficiently
- Society must receive and recognise sufficient return from the user, producer and grower industries through financial, employment, environmental or other benefits to allow it to continue.

If any of these conditions are not met over time, the industry cannot be sustainable.

As is evident from these conditions, a sustainable solid products industry cannot develop in isolation. Assuming that the broad user and societal requirements of industry do not change significantly, it can only develop in tandem with a sustainable plantation hardwood growing industry focused on producing a resource suitable for solid wood products.

8.1. Timber users and demand

Timber and other solid wood products are fundamentally building materials and their use is strongly related to the level of building activity, particularly domestic construction (ANU Forestry 2002). The building industry is not homogenous, and demand, price sensitivity and selection influences vary widely between sectors. The speculative and 'first' home market and industrial construction is generally the most price sensitive. The second home market is less price sensitive with selections strongly influenced by fashion and longer term trends of comfort and amenity. The quality and cost of work in the commercial sector ranges from pragmatic and inexpensive to very high quality and expensive. It appears the influence of fashion and longer term design trends increase with the average cost of work per m^2. Generally, commodity products of any type tend to be very competitively priced while quality differentiated products tend to sustain a higher and less variable price.

While price reactive, the building industry is also relatively conservative. New products are generally accepted slowly and established ones can be particularly resilient. For example, LVL was first manufactured in Australia in about 1984. However, it took well over a decade for it to achieve the general market acceptance it now enjoys. Conversely, there are strong loyalties to established species which can underpin demand.

The sensitivity of demand to the price of hardwood or substitutes is unknown. It is generally understood that demand is affected by changes in building codes, standards and fashion. However, there are not statistics available to quantify the sensitivity of any of these changes.

8.2. Production of solid hardwood products

It is not possible to establish a profitable solid hardwood wood products industry unless a suite of product areas is maintained. Even a pruned tree will have a very large proportion of knotty wood, both inside the clear wood section and above the pruned log length. Profitability assessments need to take into account the total tree or plantation product recoveries, costs, values. However, assessment outside of solid wood products is beyond the scope of this report.

Solid hardwood products in Australia are manufactured by private companies structured to maximise profit. Generally, this means maximising the difference between the average price of the products they sell and the cost of making those products. While this may be achieved by making a high price product, it can just as easily be achieved by making a low price product at a very low production cost.

Most solid hardwood wood products are sold to the building industry and as such they are subject to the same requirements and market influences as that industry. Structural products are generally sold into the price competitive commodity market. There is greater differentiation with appearance and high durability structural products but they still have to compete against similar products and perform satisfactorily.

Generally, only very broad statistics are available for the production or markets for hardwood products in Australia. These are discussed in Section 1 and 2. The split of production between industrial, structural and appearance wood currently or over time is unknown. The general balance between production costs and returns is also generally unknown as companies are particularly reluctant to provide this information. As most companies control the production process from acceptance of the log to dispatch of final product, these figures cannot readily be assembled by pricing component steps. This is unlike tree growing, where the constituent costs can be determined by surveying companies or contractors. Prices received by companies for solid wood products are public and reported in Section 2. Naturally, this lack of information restricts detailed analysis of profitability. Only general qualitative analysis is possible.

The profitability of sawn hardwood production in Australia is strongly related to the target market, appearance or structural, log quality and production technology.

To maximise return, production for appearance products generally focuses on producing the maximum value of product rather than the maximum volume. As discussed in Section 2, a piece of *Select* appearance product can attract a price 50-75% higher than a structural hardwood product of nominally the same size. However, the cost of production of the two in a general mixed production mill before dry milling may not be significantly different, especially in collapse-prone ash species timber. Both products have to be sawn from the log, graded, racked and dried. The cost of sawing can be lowered only if the whole log is designated as structural product and milled efficiently for volume. The cost of drying can be lowered only by predrying a structural product at a faster rate or selling it unseasoned if suitable markets can be found. After final drying, production costs between appearance and structural material can diverge considerably, as the appearance timber is milled and handled carefully to preserve its value.

A greater influence on production cost can be the number of pieces to be handled. The cost of processing greater quantities of small logs or small pieces of timber will generally be higher than processing an equal volume of larger logs and pieces.

Log quality and size generally determine the amount of high value appearance material recovered per unit of material processed and the number of pieces that have to be handled to produce that volume. For larger, high quality logs, the recovered proportion of larger appearance material can be high and structural material relatively low. This ensures a relatively high average product value. However, as log quality and size falls, the proportion of non-appearance product increases and overall recovery and average value of production falls. Also, with generally more, smaller pieces to handle, the cost of production can rise.

As shown in Figure 8.1, as the amount of appearance material as a proportion of total recovery falls, the average value of production can fall much faster than the average cost of production. Any mill receiving a mixed resource from native forests addresses this problem daily, offsetting poor recovery from some logs with better recovery from others. However, they can only sustain this if the average log quality is satisfactory. With a plantation resource, resource variability should decrease and this should allow production efficiencies, decreasing the average cost of production and increasing recovery. However, if the quality of the resource is not suitable and recovery of appearance product low, the economics of processing the resource at all for appearance products can be in question.

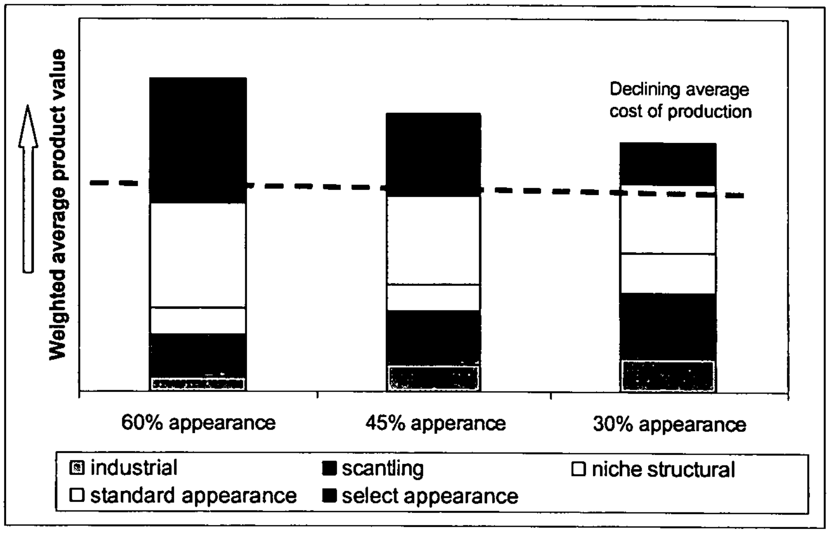


Figure 8.1. Average product value against average cost of production

In production, almost all of a log finds some use. However, recovery off the saw is generally only between 30-40% of the log volume, with the remainder going to wood chips or sawdust. Profitable markets must also be found for these products.

It is very difficult for structural hardwood products to compete directly against sawn or engineered softwood products. Donnelly (2003) observed that eucalyptus wood products are likely to be manufactured at higher costs than those of conifers. Feed speeds in eucalypt sawmills are typically about half of those in comparable conifer mills and drying time is always considerably longer. Also, as hardwood and softwood structural products are often directly comparable in a competitive and price sensitive market place, it is unrealistic to expect that hardwood can maintain a significant premium over softwood except in specific high strength or high durability applications or regions with an established market preference for hardwood. With the price of production higher and no major differentiating influences to ensure a premium in the remainder of the market, trends for softwood to replace hardwood in structural markets are likely to continue. This does not mean that some producers will not profitably produce and sell structural hardwood products, as either a by-product of producing appearance products or as specialist high strength or high durability structural products producers. However, it is unlikely that producing structural products will be the basis of a long term and profitable industry.

8.3. Profitability in growing

Both the public and private sectors are involved in growing plantation hardwoods. These sectors view sustainability and profitability in different ways. Private companies are structured to maximise financial profit and must do so in a period of time acceptable to their owners or shareholders. Notwithstanding the operations for corporatised forestry agencies, the public sector can maintain a longer and much broader view and can include

non-financial environmental and social benefits in its assessment of long term profitability (Australian Greenhouse Office 2001).

Unlike assessment of hardwood production, there has been considerable work on the productivity and profitability of growing a hardwood resource. Using an available modelling program, one set of scenarios was tested for this review. The projected log outturns are included in Section 7, while the profitability assessment is included below.

While these scenarios show that managing a plantation for high value sawlogs provides the best long term return under the assumed conditions, this does not appear to reflect the decisions that practitioners are making on the ground. Currently the public sector, through state forestry agencies or joint ventures controls most sawlog managed plantations. Often, these are part of strategies to make up for reducing log availability from native forests. The private sector is generally managing the plantations under its control for pulpwood. Demonstrably, this sector does not feel that returns will be maximised by pursuing a sawlog regime, or they have yet to be convinced that it will. A detailed assessment of this is beyond the scope of this report and the FWPRDC has funded a separate report on impediments to investment in sawlog rotation timber plantations.

However, reasons put forward by industry members during this review include:

- The value of products generated over the life of a high-value sawlog managed plantation is generally unknown. This promotes uncertainty in the value of the crop and the viability of the process. One public Australian study has shown very positive product recoveries but no similarly successful local studies have been reported.
- Government is active in both plantations and native forests and the price it may charge for logs in the future may distort the market.
- Investors may buy shares in a multi-age estate with established cash flows and returns but are cautious of a start-up industry.
- If investments are tied to one particular group of trees, the combinations of risk are too centralised.
- Taking about 25 to 30 years to grow, trees suitable for sawn timber have the longest cycle of any renewable resource or crop. This generates increased:
    - corporate and sovereign risk for the company
    - physical risk for the crop from drought, bushfire, parasites and disease.

The first of these reasons is the most relevant to this review. Currently, logs from plantations are apparently being supplied at a price that allows processors to make a return. This is probably at a discount to the real cost of producing the logs. The current owners generally did not fund the establishment of these plantations and their current sell price likely reflects their costs and the price they paid to the original owners for the estate.

However, for a sustainable plantation hardwood products industry to develop, the eventual price paid for logs grown specifically for high value products must cover the true cost of production of the log and reflect the value of the products that can be produced from the logs. Currently, the former can be quantified, but the latter cannot.

8.4. Economic analysis of the plantation hardwood industry

Both public and private sector tree growers routinely evaluate the financial returns from investing in various tree growing endeavours and the returns to undertaking particular genetic improvements and silvicultural interventions. These studies generally take the form of a simple Net Present Value (NPV) or rate of return analysis and focus on the financial aspects of timber growing. From an investor's perspective, the revenues

expected from tree growing must be sufficient to cover the cost of all production factors used including the land and the return that could alternatively have been earned on capital funds had they been applied to the best alternative investment opportunity of similar risk.

For example, Gerrand, Prydon and Fenn (1993) assess the NPV for various eucalypt plantation regimes in Tasmania under a range of assumed economic and biological parameters. Smethurst et al. (2004) use NPV analysis to determine the range of economic and physical conditions under which various fertilisation programs are economically justified in Tasmanian hardwood plantations. Sands, Rawlins and Battaglia (1999) assess the profitability of irrigating *E. globulus* in the Murray-Darling Basin.

The results of these and similar studies show the wide range of potential profitability and the sensitivity of financial returns to assumptions about input costs, yields, product recovery and market prices. This suggests that results of such studies must be interpreted within the context of the prevailing conditions and assumptions made. Generally however, costly investment in silvicultural activities aimed at improving sawlog yields and wood quality are warranted only on higher quality sites and where market prices are assumed to reflect improved recoveries, and where wood product users recognise and are willing to pay a price premium for a higher quality product.

Studies of the economic returns to growing hardwood plantations generally focus on the private financial aspects of investment. From a regulatory and public policy perspective, an evaluation of such investments needs to reflect the broader range of social costs and benefits, and should account for costs and benefits that might not be recognised or captured by the private sector. As a example, Sands et al. (1999) recognise but do not quantify the possibility of plantations producing a stream of social benefits as a part of a net CO^2 sink and as a means of lowering the water table in salinity prone regions.

Analogous studies are also routinely carried out to evaluate the economic returns to other stages in the production process, such as harvesting and log handling, processing and drying systems. For example, Leggate, Palmer and Walduck (undated) report on the financial returns, measured as a percentage return on cost, to milling plantation grown *E. cloeziana* in Queensland.

The capacity to model forest growing and processing systems has been substantially improved in recent years, and the integration of this capacity into accessible management tools continues to be an important research focus. For example, the Farm Forestry Toolbox provides landowners with an accessible tool for assessing the returns to forest management alternatives. This program was used to compare the financial returns to the five following hardwood silvicultural alternatives:

- Low value fibre management: no thinning or pruning - generates pulp logs and some unpruned sawlogs (**fibre mMAI27**).
- High value management with pruning and a commercial thin for fibre at age 9 years (**SL CT09 mMAI27**).
- High value management with pruning and early non-commercial thinning (**SL NCT mMAI27**).
- Medium value management with no pruning and commercial thinning (**SL CT09 UP mMAI27**).
- High value management with low establishment stocking (500 stems per hectare), pruning and early non-commercial thinning (**SL NCT 500sph mMAI27**).

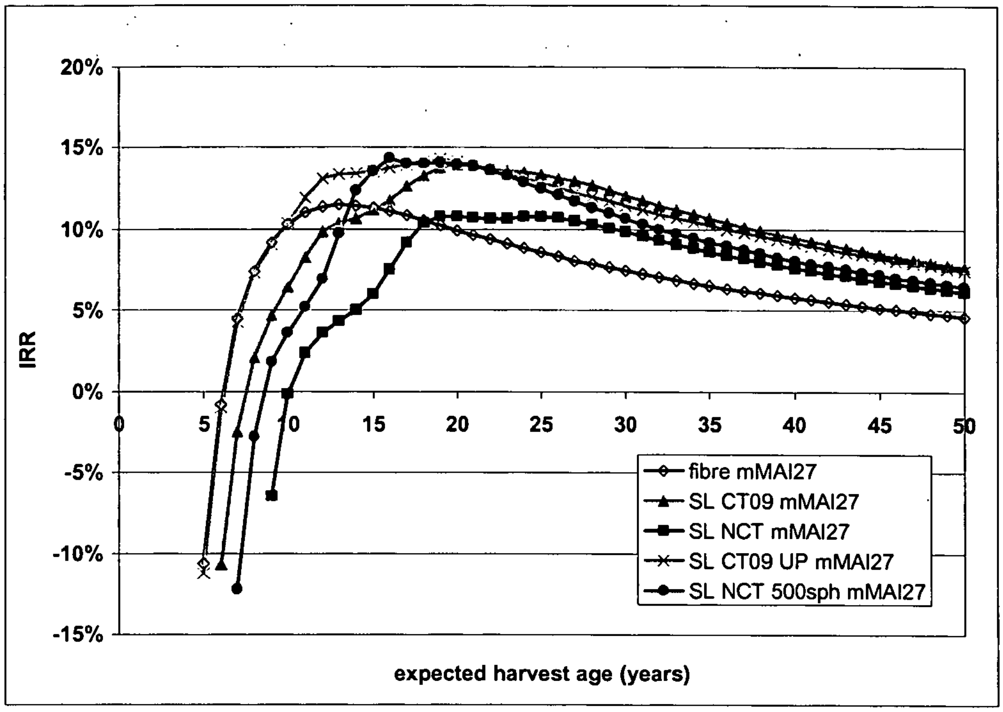


Figure 8.2. IRR with expected harvest age, by silviculture, for a moderate growth site (MAI_{10} 22m^3/ha/year). Based on predicted recovery by log-grade (assumed log grades depicted in Table 8.1) estimated using a modified version of the Farm Forestry Toolbox growth model (V.4.9 with modifications), IRR calculations in Microsoft Excel 2000

For rotation ages less than 13 years, low value management (no thinning or pruning) offers the greatest Net Present Value. At rotation lengths greater than 13 years, low initial stocking combined with pruning and non-commercial thinning provides the greatest Net Present Value.

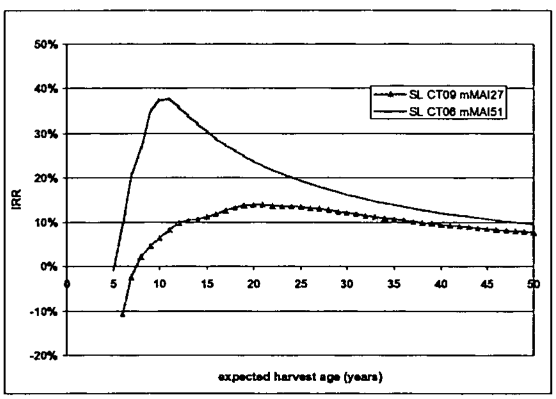


Figure 8.3. Predicted IRR for sawlog regime with commercial thinning for MAI_{max} of 27 and 51 m^3/ha/year. Predictions after FFT4 (V.4.9 with modifications)

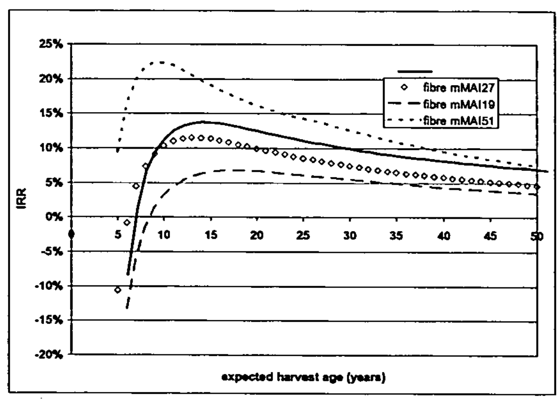


Figure 8.4. Predicted IRR for fibre regime with commercial thinning for MAI_{max} of 19, 27 and 51 m^3/ha/year. Predictions after FFT4 (V.4.9 with modifications)

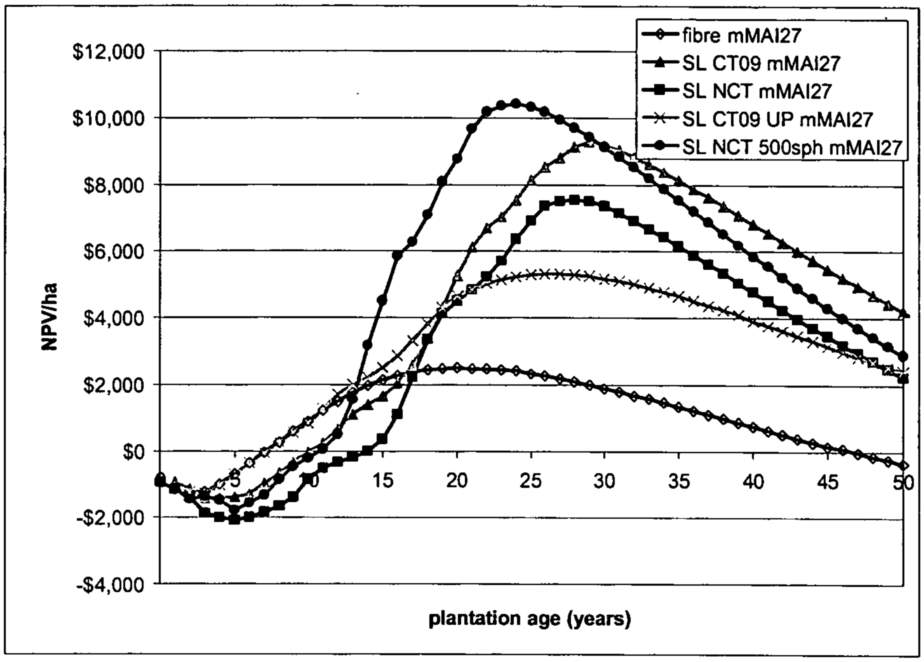


Figure 8.5. Net Present Value with stand age by silviculture for a moderate growth site (MAI_{10} 22m^3/ha/year) - discount rate 5%. Based on predicted recovery by log-grade (assumed log grades depicted in Table 8.1) estimated using a modified version of the Farm Forestry Toolbox growth model (V.4.9 with modifications), NPV calculations in Microsoft Excel 2000

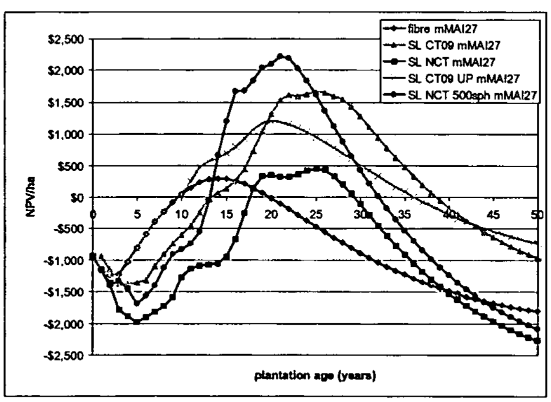


Figure 8.6. NPV at 10% discount rate

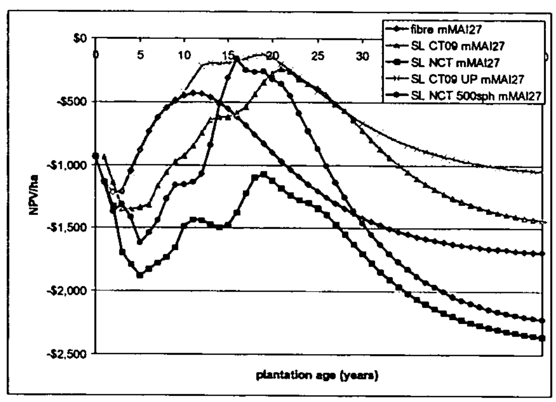


Figure 8.7. NPV at 15% discount rate

Table 8.1. Assumed log grades: dimensions and values

log grade code	log grade	Diameter UB (cm)		Length (m)		value
		minimum	maximum	minimum	maximum	(/m3)
S1_P	sawlog category 1, pruned	40	no max.	3.6	11	$150
S3_P	sawlog category 3, pruned	35	no max.	3.6	11	$90
S3UP	sawlog category 3, unpruned	35	no max.	2.9	11	$50
SHUP	sawlog, unpruned, Hew Saw	24	35	3.5	11	$35
Pulp	pulpwood	7	no max.	2.4	11	$20
X	waste					

The $150/m^3 set for Tasmanian category 1 sawlogs is higher than current native forest log prices. However, it is nominal price for high-value export pine logs.

8.5. Predicted log volumes and log values with age and silviculture

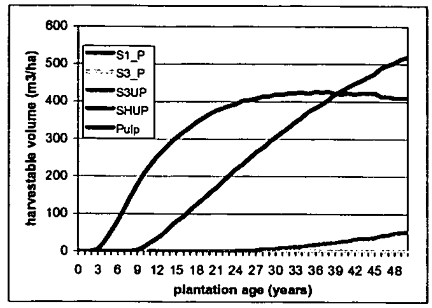
fibre mMAI27
Low value, unpruned, unthinned, moderate MAI
MAI(10) 22 m3/ha/yr; Maximum MAI(volume) 27 m3/ha/yr

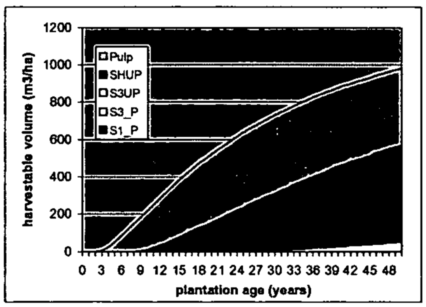
Management

age 0	established at 1,100 sph

Rotation length indicators

maximum MAI(volume)	age 19 years
maximum NPV(i=5%)	age 20 years
maximum MAI-log-value	age 26 years
maximum MAI-NPV	age 15 years





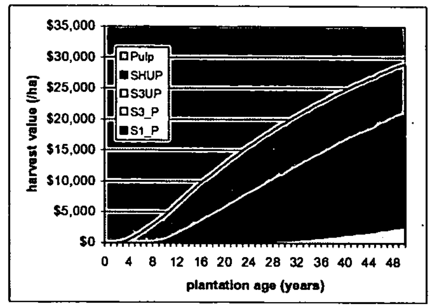


Figure 8.8. Low value, unpruned option (fibre mMAI27)

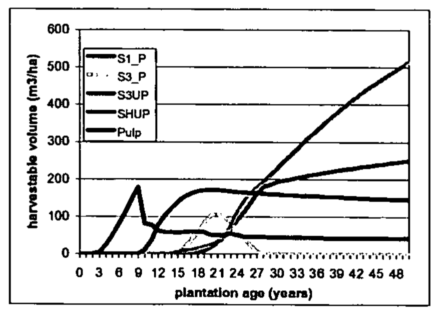
SL CT09 mMAI27
High value, commerial thin age 9, moderate MAI
MAI(10) 22 m3/ha/yr; Maximum MAI(volume) 27 m3/ha/yr

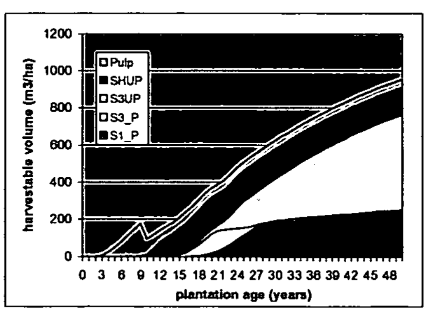
Management

age 0	established at 1,100 sph
age 2	prune 350sph to 2.1m
age 4	prune 250sph to 4.2m
age 5	prune 200sph to 6.4m
age 9	thin to 200sph - 111m3/ha pulpwood

Rotation length indicators

maximum MAI(volume)	age 25 years
maximum NPV(i=5%)	age 28 years
maximum MAI-log-value	age 30 years
maximum MAI-NPV	age 25 years





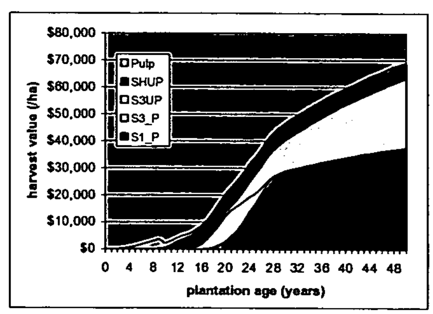


Figure 8.9. High value, commercial thin age 9, pruned (x3) (SL CT09 mMAI27)

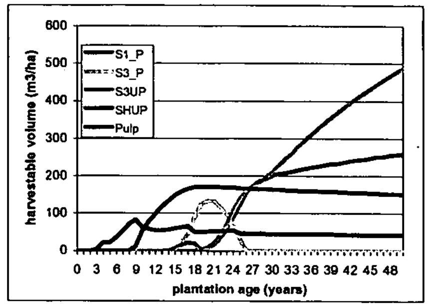
SL NCT mMAI27
High value, non-commerial thin age 3 & 4, moderate MAI
MAI(10) 22 m3/ha/yr; Maximum MAI(volume) 27 m3/ha/yr

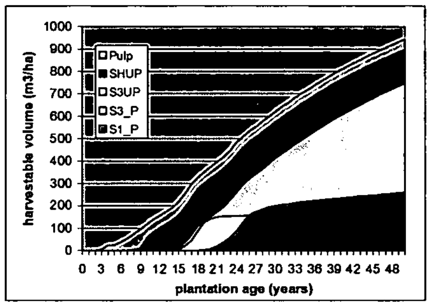
Management

age 0	established at 1,100 sph
age 2	prune 350sph to 2.1m
age 3	prune 250sph to 4.2m, thin to 600sph
age 4	prune 200sph to 6.4m, thin to 200sph

Rotation length indicators

maximum MAI(volume)	age 30 years
maximum NPV(i=5%)	age 28 years
maximum MAI-log-value	age 30 years
maximum MAI-NPV	age 26 years





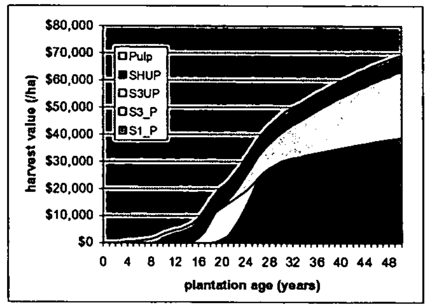


Figure 8.10. High value, non-commercial thin age 3 and 4, pruned (x3) (SL NCT mMAI27)

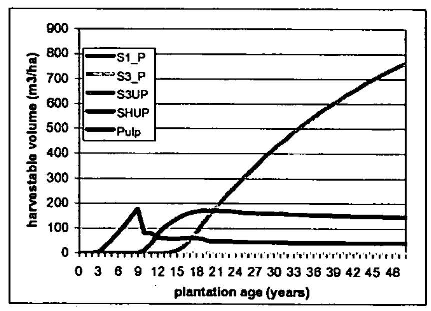
SL CT09 UP mMAI27
High value, unpruned, commerial thin age 9, moderate MAI
MAI(10) 22 m3/ha/yr; Maximum MAI(volume) 27 m3/ha/yr

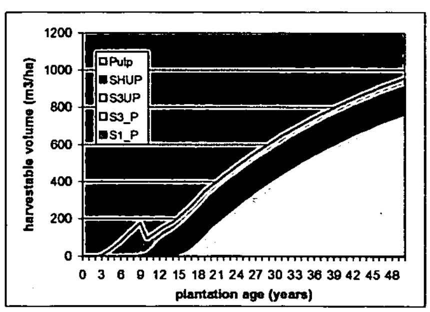
Management

age 0	established at 1,100 sph
age 9	thin to 200sph - 111m3/ha pulpwood

Rotation length indicators

maximum MAI(volume)	age 25 years
maximum NPV(i=5%)	age 27 years
maximum MAI-log-value	age 36 years
maximum MAI-NPV	age 20 years





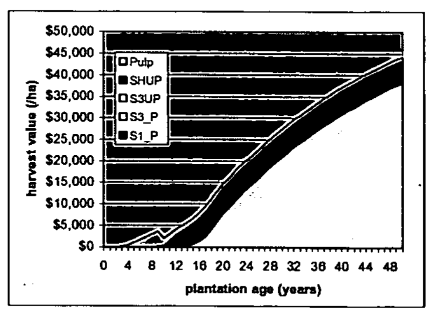


Figure 8.11. Medium value, commercial thin age 9, not pruned (SL CT09 UP mMAI27)

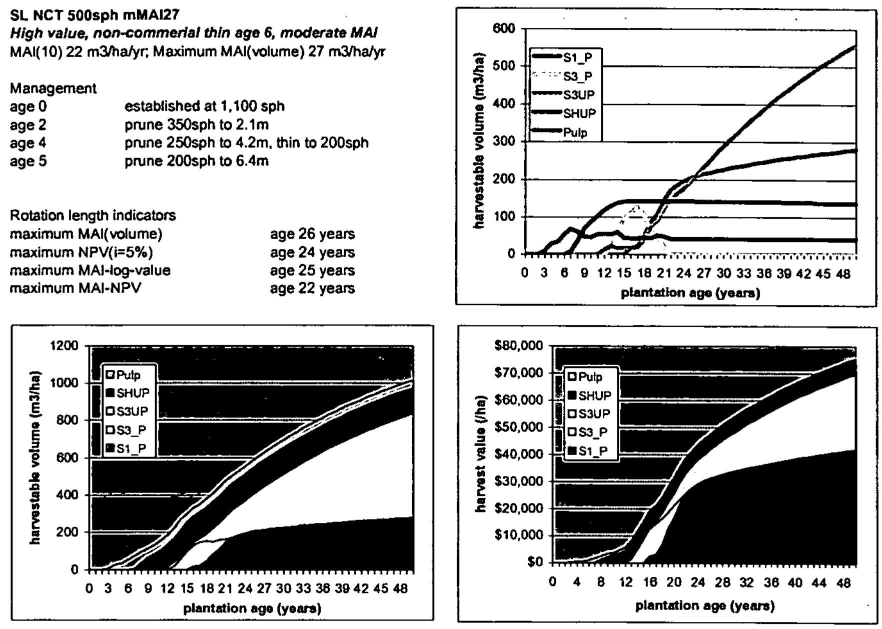


Figure 8.12. High value, low establishment stocking (500 sph), non-commercial thin at age 4 (SL NCT 500sph mMAI27)

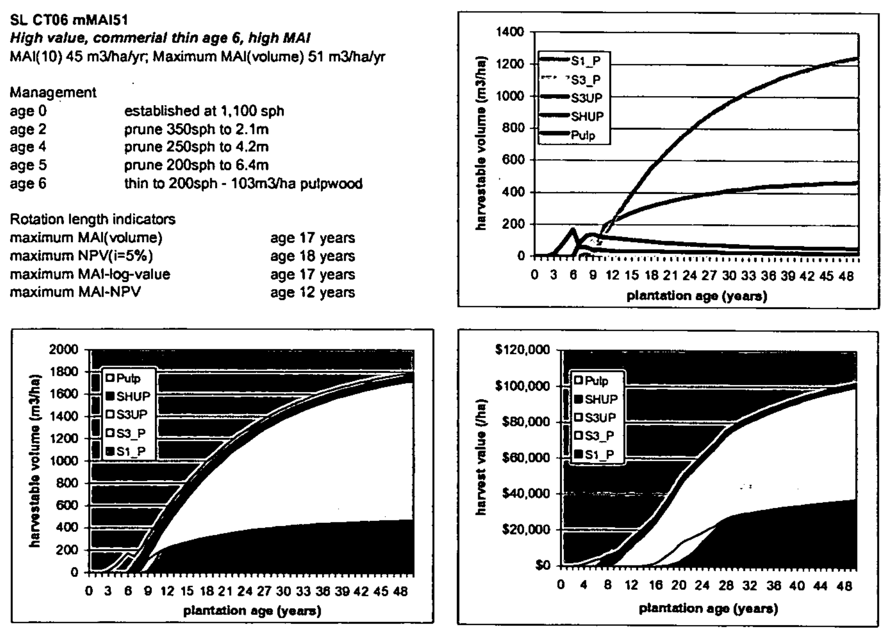


Figure 8.13. High value with high growth rate (MAI_{10} 45m^3/ha/yr), commercial thin age 6 (SL CT06 mMAI51)

The growing costs used were compiled for the purpose of this report and represent best estimates based upon experience in Tasmania. Costs are indicative only and may vary with site and growing region.

Table 8.2. Growing costs used in Net Present Value analysis

fibre mMAI27

Age	operation	cost/ha
annual	rent	$100
0	spray	$80
0	pest control	$35
0	plants	$250
0	clearing	$200
0	ripping/plough	$160
0	planting	$110
1	fert/pest control	$135

SL NCT mMAI27

Age	operation	cost
annual	rent	$100
0	spray	$80
0	pest control	$35
0	plants	$250
0	clearing	$200
0	ripping/plough	$160
0	planting	$110
1	fert/pest control	$135
2	prune 350sph to 2.1m	$150
3	prune 250sph to 4.2m / thin to 600sph	$550
4	prune 200sph to 6.4 / thin to 200sph	$400

SL CT09 mMAI27

Age	operation	cost
annual	rent	$100
0	spray	$80
0	pest control	$35
0	plants	$250
0	clearing	$200
0	ripping/plough	$160
0	planting	$110
1	fert/pest control	$135
2	prune 350sph to 2.1m	$175
4	prune 250sph to 4.2m	$250
5	prune 200sph to 6.4m	$300
9	thin to 200sph (111m3 fibre)	$0

SL CT09 UP mMAI27

Age	operation	cost
annual	rent	$100
0	spray	$80
0	pest control	$35
0	plants	$250
0	clearing	$200
0	ripping/plough	$160
0	planting	$110
1	fert/pest control	$135
9	thin to 200sph (111m3 fibre)	$0

SL NCT 500sph mMAI27

Age	operation	cost
annual	rent	$100
0	spray	$80
0	pest control	$35
0	plants	$250
0	clearing	$200
0	ripping/plough	$160
0	planting	$110
1	fert/pest control	$135
2	prune 350sph to 2.1m	$210
4	prune 200sph to 4.2m / thin to 200sph	$425
5	prune 200sph to 6.4m	$340

SL CT06 mMAI51

Age	operation	cost
annual	rent	$100
0	spray	$80
0	pest control	$35
0	plants	$250
0	clearing	$200
0	ripping/plough	$160
0	planting	$110
1	fert/pest control	$135
2	prune 350sph to 2.1m	$175
4	prune 250sph to 4.2m	$250
5	prune 200sph to 6.4m	$300
6	thin to 200sph (96m3 fibre)	$0

fibre mMAI19

Age	operation	cost
annual	rent	$100
0	spray	$80
0	pest control	$35
0	plants	$250
0	clearing	$200
0	ripping/plough	$160
0	planting	$110
1	fert/pest control	$135

fibre mMAI51

Age	operation	cost
annual	rent	$100
0	spray	$80
0	pest control	$35
0	plants	$250
0	clearing	$200
0	ripping/plough	$160
0	planting	$110
1	fert/pest control	$135

The continued development of management tools such as the FFT is a priority if resources are to be directed to the opportunities that provide the greatest return. This involves further clarifying the links between silvicultural treatment, wood properties, log quality, standing yield, product recovery and financial return.

Predicting future log prices

Investors are interested in trends in real log prices as part of the process of evaluating the profitability of current forest investment decisions. Governments are also interested in these trends as changing real prices can signal possible future supply shortfalls or surpluses which may be of strategic importance.

In a competitive market, prices contain important information both about the value buyers place on a good and the cost of producing the good. Prices in turn provide signals to buyers and sellers and ensure that a good is produced by those who can do so at least cost and that it is purchased by those buyers who value the good most highly.

Competitive prices also contain valuable information about the attributes of goods that are valued most highly by buyers. It is this competitive price mechanism that ensures that markets produce the 'right goods in the least cost way'.

Hardwood logs have traditionally not been traded in competitive markets in Australia. The historical dominance of the Crown in growing long rotation forests and plantations has meant that log prices have often reflected criteria such as the cost of growing or rate of return criteria for government agencies and have not reflected the market forces of supply and demand. Endeavours to develop auction-based log sale systems, while encouraging, are still in their infancy and log prices in Australia generally can not be relied upon to convey accurate information to producers about demand and supply conditions.

Publicly available data on hardwood log prices in Australia is very limited. An ANU Forestry Market Report (December 2002) reports results of an historical analysis of prices for hardwood logs from Forestry Tasmania sales from native forests over the last 20 years that suggest the following:

- Native forest hardwood sawlog stumpage increased in real terms; native forest hardwood pulp log stumpage fell slightly in real terms.
- Native forest hardwood sawlog stumpage increased at a much faster rate than did agricultural prices.
- Native forest hardwood sawlog stumpage increased faster than the price of hardwood structural timber.

It is generally accepted that the long term outlook for future log prices in Australia will mirror trends in the global market outlook. The task of forecasting future global log prices is complex and must account for a range of factors including technological change, population growth, substitution possibilities, new production capacity and national and global political factors. It is not surprising that there is no consensus on future trends in real log prices. Some studies suggest that real prices will continue to grow, while others foresee a decline in real log prices, or a fall for some log grades but not for others (ANU Forestry Market Report September 2002).

Predictions of rising real prices are often underpinned by the assumption that log demand is price inelastic; implying that a rise in price will be accompanied by a less than proportionate increase (decrease) in quantity demanded. While empirical studies of price elasticity generally confirm this, they reflect short run responses. There is less empirical evidence of the inelasticity of demand for logs in the long run when the possibilities for substitution are greater.

There is also a need to predict the future demand for various wood and log characteristics and the structure of premiums for wood of various qualities. In an age in which forests can be managed for the production of quality-related characteristics and processing technologies adjusted in response to the nature of the fibre-input, 'competitiveness' may rely heavily on the ability to match the nature of the resource with the technical requirements of end-use products. Identifying the dimensions of wood quality (as done in Section 6 of this report) and establishing the relative values of particular wood quality characteristics are problems which should be given high research priority by forest scientists, managers, engineers and economists.

Despite characteristic level analysis being widespread in economics, and the problem of 'product design' with which forest managers are confronted is conceptually no different from that faced by the producer of any quality differentiated product, the application of such models and methods is uncommon.

8.6. Optimum rotation length

There are a number of possible criteria for determining optimum rotation length. These are listed below with estimated optimums for the modelled regime involving early pruning and non-commercial thinning (**SL NCT mMAI27** - Figure 8.10).

- maximum Mean Annual Increment of volume (age 30 - Figure 8.14)
- maximum Mean Annual Increment of stand value (age 30 years - Figure 8.15)
- maximum Net Present Value (NPV) over the life of the plantation (harvest at 28 years - Figure 8.16)
- maximum Internal Rate of Return (IRR) (harvest at 18 to 26 years - Figure 8.17).

Figure 8.14. Total standing volume with age, Mean Annual Increment (MAI) and Current Annual Increment (CAI) with age

Maximum MAI: age 30 years

Maximum CAI: age 16 years

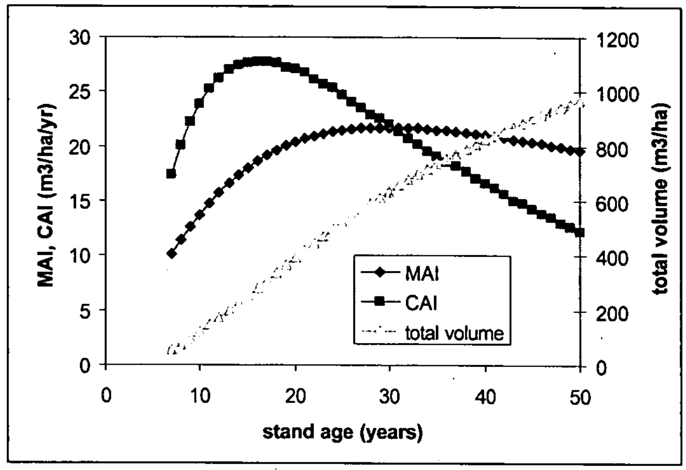


Figure 8.15. Total standing log value with age, Mean Annual Increment of total log value (MAI value) and Current Annual Increment of total log value (CAI value) with age

Maximum MAI value: age 30 years

Maximum CAI value: age 24 years

(See also Figure 7.10 which depicts expected log-grade outturn with age for managed-for-sawlog plantations of *Eucalyptus grandis* in Uruguay)

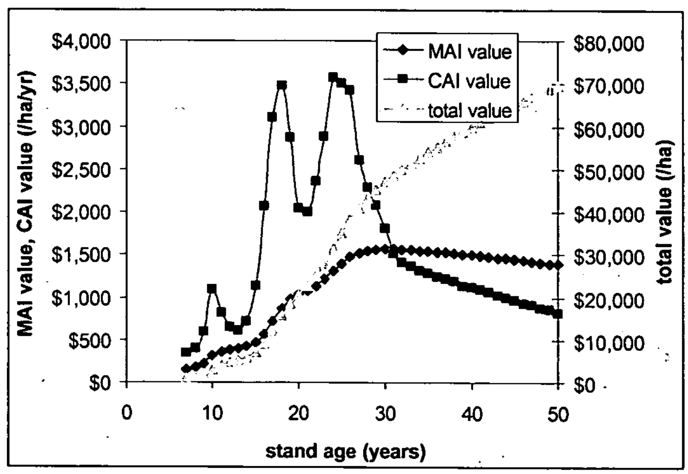


Figure 8.16. Net Present Value (i=5%) at time of establishment versus stand age at harvest, MAI and CAI of NPV with expected harvest age

Maximum NPV: harvest at 28 years

Maximum MAI NPV: age 26 years

Maximum CAI NPV: age 18 years

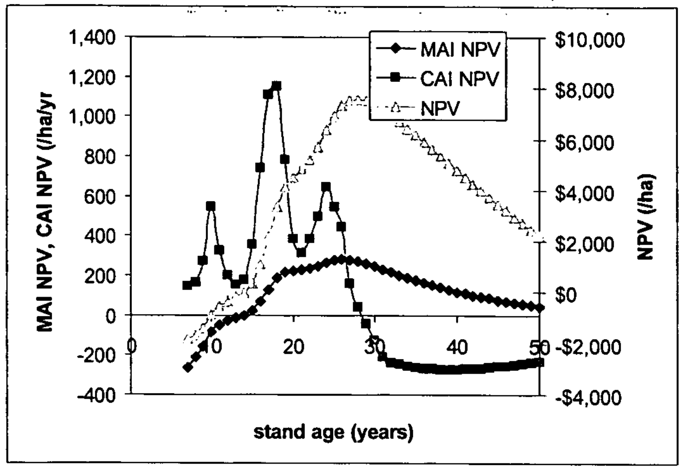


Figure 8.17. Internal rate of return versus stand age at harvest, MAI and CAI of IRR with expected harvest age

Maximum IRR: harvest at 19 years

Maximum MAI IRR: age 18 years

Maximum CAI IRR: age >10 years

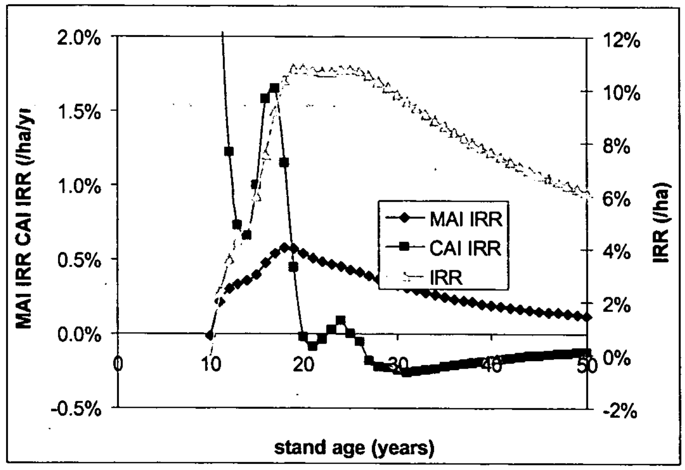


Table 8.3. Estimated internal rate of return, and mean annual increments for total volume, total sawlog volume and large pruned sawlogs, versus stand age at harvest, for managed-for-sawlog plantations of *Eucalyptus grandis* in Uruguay. Figure reproduced from presentation by Shield (2004). (Estimated log grade outturns with age are depicted previously in Figure 7.10.)

ROTATION LENGTH	INTERNAL RATE OF RETURN	TOTAL M.A.I.	SAWLOG M.A.I.	LARGE PRUNED SAWLOG M.A.I.
YEARS	PERCENT	M^3/HA./AN.	M^3/HA./AN.	M^3/HA./AN.
16	22.4	31.5	23.9	6.3
17	21.7	31.4	24.3	7.9
18	21.1	31.2	24.4	9.1
19	20.4	31.0	24.7	10.0
20	19.8	30.8	24.7	10.5

9.0. Technological advance

This is not the first time that Australia's timber producers and users have adapted to a new wood resource. In the 1970s researchers, producers and the market had to deal with a plantation softwood resource that presented seemingly insurmountable challenges. Eventually, these were overcome as perception changed, opportunities were exploited and new technology imported or developed and implemented. This provides useful lessons in adapting to a plantation hardwood resource.

Processing a log into a solid wood product is essentially a simple process. The log is trimmed, hewn, sawn, peeled or sliced and the resulting pieces are used as they come off the logs or are dried, shaped and graded further before use. Australia's eucalypt and other natural hardwoods have been milled since at least European colonisation of the continent. Major technological advances took place between the 1930s and 1950s, especially in processing collapse prone Ash species (Greenhill 1938) and established the production processes that fundamentally remain in use today. Change since that time has been incremental. There are a number of processes that have been adopted in some hardwood producing regions but not in others. While their benefit may be thought marginal for a native forest resource, they will probably be essential for milling a plantation resource. For example, it is highly likely that the sapwood of all lyctus-susceptible species of a plantation resource will be left on the board and the boards then treated.

Further technological advance can influence the productivity and profitability of growing and processing eucalypt hardwood from both natural and plantation sources.

In addition to the likely developments discussed below, a second wave of computerisation is likely to affect the industry. Personal digital assistants (PDAs), bar coding and automated data collection techniques, and production optimisation software are currently being developed for industry (Nolan 2002). These have the potential to improve process and information management and increase productivity significantly.

9.1. Likely developments

The aim of most likely developments is to grow and deliver uniform logs that suit efficient processing and wood drying systems. These include:

Silviculture

- Improvement through tree breeding: desirable heritable characteristics can be improved by breeding and undesirable ones minimised over the long term. Breeding should improve growth, minimise the size and severity of the juvenile core; reduce shrinkage properties that lead to warp and checking.
- Clonal propagation: this reduces variation between trees in a stand and opens up the potential for optimising processing of more uniform logs. It will not necessarily be possible in all species.
- Better understanding of the interactions between site, species and silviculture so that the process can be optimized for growth success.

Harvesting and log grading

- Means of sorting logs to exploit within-stand variation. This may be by using the speed of sound in the log or similar non-destructive techniques as a proxy for structural and drying characteristics.

Processing

- Improved and alternative sawing equipment and processes. These can reduce processing costs, increase recovery and improve competitiveness.

- Means of sorting boards using non-destructive evaluation techniques. This may enhance drying efficiency and reduce degrade.
- Novel drying kilns. Advances in kiln technology and new types of kilns such as vacuum kilns may reduce drying time and degrade considerably.
- Automated visual and colour grading. These may allow more consistent sorting of product for key markets.
- Post processing quality control processes, such as non-destructive evaluation of degrade such as internal checks, inline moisture content monitoring, and in line strength grading.

9.2. Experimental development

There are several experimental developments that hold promise for either improving or revolutionising production. A major one of these is the microwave pretreatment of boards or logs being developed at the CRC for Wood Innovation. This process proposes to use intensive microwave radiation to modify the structure of wood, reducing variability and providing improved physical properties and technological attributes. Inside the wood, microwave energy is converted to heat, creating steam pressure in the wood cells. Ray cells have thinner walls in comparison with the main structural tissues of wood (tracheids, libriform fibres and vessels). Under high internal pressure the thin-walled ray cells rupture to create micro-voids. These micro-voids form pathways for easy transportation of liquids and vapours. It is proposed that they allow water out during a much accelerated drying process and preservatives or glues in. Microwave modification protocols are planned to suit different applications, such as conditioning for relaxation of growth stresses in logs, speeding up hardwood drying, facilitating uptake of preservatives, and generation of wood-resin composite products.

9.3. Limitations on technical advance

Each technological advance can potentially increase recovery of usable product from the log and reduce the unit cost of production. This can make growing and milling plantation hardwoods more profitable, more competitive or both. However, none of these advances are likely to change the two most important market drivers for solid hardwood products, namely:

- the dominant demand for low feature wood in appearance applications
- the cost competitiveness of exotic softwood products over hardwood ones in the commodity structural market.

Foreseeable technological advance will not turn a knotty piece of timber into a low feature one without some form of docking and gluing, and so is unlikely to remove the necessity to prune and grow the logs suitably.

10.0. Discussion

This review explores influences and impediments on a solid products industry's ability to profitably process a plantation hardwood resource. From Australian and international practice, it is possible to determine that plantation eucalypts can be processed into solid timber products, appearance and structural sawn products, and appearance and structural veneer products. However, it is not possible from the work and experience at hand to determine if this can be done profitably on a sustainable industry basis in Australia.

There are several major themes being balanced in this report, namely:

- the length of time that it takes for a planted seedling to be eventually converted into a usable product
- the diversity of the industry and its resource base.

The growth cycle for trees is perhaps the longest of any renewable resource. To grow a plantation eucalypt resource suitable for a solid hardwood products industry, it is necessary to balance estimates of the likely result of genetic and silvicultural decisions over a 20 to 30 year period, and the probable processing and market requirements for hardwood at the end of that period. The tree grower bears the majority of risk these variables present as they must determine and pursue what they believe to be the most appropriate wood quality strategy. These can include:

- exploiting the many genetic and silvicultural opportunities to produce a resource with properties that are desirable for particular end-uses. This relies on predicting the future value for wood and log quality traits for various species
- aiming to maintain a 'high-quality' resource across species to provide flexibility in the face of changing end-use needs and ensure a place in premium markets
- focusing on producing fibre and relying on technology and market integration to make use of the material produced. As it is difficult to predict future market requirements accurately, more demanding final product specifications may be met with technological rather than biological or silvicultural solutions. This means that wood and log characteristics associated with high end-use flexibility will be prized.

The current hardwood production industry and its product ranges are diverse, and that diversity will probably continue. Production strategies for processing a similar resource range from sophisticated milling and drying approaches to simply sawing the logs as cheaply as possible and selling the green product. While both are valid enterprises and can make a profit, it is likely that the former will provide a more reliable basis for a sustainable industry than the later. Also, there is a diverse range of hardwood species being grown in plantations. As each has differing wood quality and properties, they present different marketing and production opportunities. For example, highly durable species are suitable for external applications without treatment.

10.1. Current industry position

The solid wood products industry

The Australian hardwood solid products industry is reliant on selling its product into mainly appearance and niche structural markets. Though opportunistic local markets for general structural products will remain, it is likely that hardwood's general substitution in structural applications with softwood products will continue. Export opportunities may exist in countries with a traditional hardwood preference, but assessing these is beyond the scope of this report. The industry is reliant on a log supply from a native forest resource. This supply has declined continually since the mid-1960s and log availability is likely to decline by about 23%, or 635,000 m^3, between 2001 and 2039.

The current hardwood plantation resource for solid wood products

Assuming that there are no major changes in the land use of existing native forests, the only resource that can make up this decline in log availability is plantation grown hardwood logs. Unfortunately, the broad hardwood plantation resource is being managed for a different purpose. About 83% is managed to produce fibre. As such, it will not generally produce a suitable resource for a hardwood industry hoping to maintain or expand existing markets for high value appearance products.

The remaining 17.4% of Australia's hardwood plantations are managed to produce sawlog. However, the probable log availability from these forests is likely to provide only about 15% of current log availability by 2035. In short, there are not enough plantations of the right type in the ground to make up for the projected loss of supply from native forests or increase overall supply. Also, it is highly unlikely that any of the fibre managed plantations established before 2001 can be reasonably converted to a sawlog regime. The majority of sawlog managed plantations are also owned by or established in cooperation with state agencies. The bulk of private sector plantations are largely grown for fibre.

The long rotation plantations currently being milled were originally established for fibre but left to grow on. In some cases, they have been thinned. When harvested, a large proportion is used for fibre while most of the remainder is milled as industrial wood. Only 10-15% is converted to higher value solid products. The bulk of sawlog managed plantations is relatively young with 62% less than 10 years old. As such, very little or no thinned and pruned plantations of the optimal harvest age are available for industry, or even for extensive mill trials.

Many in the hardwood production industry, who have only been exposed to milling a material originally grown for fibre, have severe reservations about the prospect of basing their businesses on converting a plantation resource into solid wood products.

10.2. Broad research results

The broad results of practice and research into converting plantation hardwood to solid wood products to date indicate that:

- logs from unthinned and unpruned stands are:
    - generally not suitable for appearance products
    - occasionally suitable for general structural products if grown on good sites;
    - generally unsuitable for high strength veneer products due to low recovery and frequent unacceptable defect. They may be suitable for general veneer products
    - suitable for milling by convention means. Reported recoveries vary considerably but are generally significantly lower than logs currently harvested from native forests
    - generally less favourable and less consistent in density, strength, durability, drying properties, and stress profile than native forest material
    - subject to significant drying degrade during initial drying
    - stress and drying problems can be prominent in a significant proportion of the material, especially *E. globulus* and *E. nitens.*
- logs from thinned and unpruned stands of self pruning species are:
    - being used for appearance products with satisfactory results but generally inferior to a native forest resource, with lower recovery in logs of the same grade
    - suitable for general structural products

- in some species and age classes, liable to significant drying degrade during initial drying
- more variability in material properties than native forest material. This may result in increased distortion.

- logs from thinned and pruned stands are:
  - rare, with little being supplied to industry. Even research trials of material of the optimal harvest age and management history are uncommon
  - generally suitable for appearance products. Recoveries can approach or even surpass those achieved from native forest material. One Australian trial has provided very promising results in observed low growth stress, milling and drying performance and overall recovery.

The broad problems in processing are:

- handling growth stress and tension wood during transporting and milling
- sorting material to cope with variations in wood properties
- increased care needed with drying, especially with collapse-prone species.

The broad results of silvicultural research and practice to date indicate that:

- Selection of site has a major influence on growth rate and wood properties of grown trees.
- Tension wood volumes and occurrence can be significantly reduced by silviculture, both in spacing treatment and fertiliser application.
- There is considerable difference between the performance of different species, and there is also species-by-site interaction: some species perform better on some sites whilst others perform better on other sites.
- There is considerable variation in most tree characteristics (growth, form, and wood properties) which can be exploited through breeding.
- Most wood properties vary with the age of the formed wood, and thus whole-tree average properties vary with age.
- There may be considerable variation in tree size and tree wood quality within a seemingly uniform stand of plantation eucalypts, particularly in a non-clonal stand. The exploitation of between-tree wood quality variation via segregation at harvesting is an avenue for better utilising grown resource.
- Increasing tree spacing (reduced stocking), both at establishment and with thinning, reduces total stand growth, increases individual tree growth, increases branch size, reduces log quality for a given log diameter; increases butt taper, increases end splitting (as a consequence of larger diameter trees), leads to higher basic density, achievement of mature-wood basic density at an earlier age, greater sapwood thickness, higher heartwood content, and higher recovery of *Select* grade sawn-timber.
- Thinning too heavily too early can reduce the value of plantation-grown sawlogs by increasing the size and importance of the juvenile core.
- Pruning increases clear-wood production provided that branches are pruned green. Green crown lifts early and may achieve 5 metres by age 4 - thus pruning must commence early (possibly age two years). Unpruned trees can produce clear-looking branch-free logs which will likely have significant sized knotty cores. A difficulty with operational pruning is that trees in a stand will vary in their development requiring either multiple visits or over- and under-pruning.

- There appears to be little value in late thinning and pruning of fibre-managed stands to increase value as pruning dead branches achieves little and the market for knotty wood is limited.
- To grow high value sawlogs or peeler-logs, early pruning and relatively early thinning is required. Thinning strategy depends on local costs and markets for pulpwood (from commercial thinning crop).

It is becoming apparent that the broad process for growing a suitable resource for solid wood products is known. It involves:

- selecting species that have growth and wood quality characteristics suited to producing solid wood products on relatively short rotation times
- planting suitably selected trees on high quality sites at a high initial stocking;
- pruning the trees at an early age to reduce the size of the knotty core and encourage the growth of clear wood. Follow up pruning is then required regularly to restrict the tree's natural response of growing large branches;
- thinning the number of trees on the site severely before canopy closure to about 150-250 stems per hectare. This reduces the aspect ratio (height to stem diameter) of the trees and probably limits the development of tension wood / growth stresses considerably
- grow the trees through to a suitable market diameter. This takes 20-35 years dependant on the characteristics of the trees and the site.

This process provides the widest possible opportunity for marketing the logs as it focuses on producing a resource for:

- appearance grade recovery for the sawn timber, with a fall-down market of structural and industrial timber
- appearance and high quality structural veneer, with fall down into internal laminates, and strand material.

10.3. Possible future position

The growth of significant areas of hardwood plantations for solid wood products can change the structure of the hardwood production industry. Currently, mill size, productivity and integration are limited due to the variability in the age, diameter and species of the resource and the constraints on production that this imposes.

If an extensive and dynamic plantation estate grown specifically for solid hardwood products is established, the resource it can supply will be more regular in species, diameter class, length and physical characteristics. With consistent supply and material availability within a reasonable transport distance, techniques can be developed and adopted to:

- sort logs and boards by key material properties and stream them to the most valuable end products
- optimise sawing, handling and drying of those products, improving recovery, reducing degrade and bringing down processing cost
- improve integration. There are likely to be considerable transport and production economies in establishing processing centres with the capacity to:
    - slice decorative and peel structural veneer
    - saw appearance and structural timber
    - assemble a range of laminated products, such as plywood, LVL and glulam
    - treat natural round and sawn products

- develop ranges of complementary products that use the parts of the tree and log unsuitable for solid wood products.

Due to the variability generated by site and growing conditions and local economic factors, the sawing and veneer industry can pursue one of two general strategies:

- Growing and milling for value
- Growing and milling for volume

Growing and milling for value

The objective of growing and milling for value is to economically produce a range of high value appearance sawn and veneer products, supported by products and services that use the logs or parts of logs that do not make appearance or high quality structural material. The probable scenario of growing and milling for value is:

Growing	A limited number of species, selected for a balance between speed of growth, suitability for location and quality of product, are grown specifically for solid wood products. They are pruned at an early age and thinned and pruned repeatedly to ensure maximum recovery of quality products.
Assessment	The timing and quality of the silviculture is certified. Logs are batched for key characteristics, tagged and directed to the correct mill (veneer, saw or treatment) for processing.
Milling	Suitable logs are cut for grade to produce the best material for the target market. Appearance sawn products are quarter or back sawn as appropriate to produce the highest visual grades. Lower grade logs are cut for volume using an optimised multi-saw arrangement to economically produce the best structural product for the market.
Drying	Appearance products are dried for value and minimum drying degrade. Structural products are dried more quickly while maintaining stability and limiting unacceptable degrade, most likely unrecoverable collapse and excessive checking.
Product range	Integrated product range founded on high value appearance products supported by niche structural, composite and treated products.

This strategy equates to an optimisation of the current production and marketing approach of many of Australia's major hardwood producers with native forest supply augmented by a more consistent plantation resource. Internationally, this is the strategy being followed by leading timber production companies in South America (Bill Leggate, 2004, pers. comm.), South Africa and the Iberian Peninsula.

Growing and milling for volume

The objective is growing to economically produce solid wood products, with the primary target product being structural products, with some complementary appearance upgrade product and industrial products lines.

Growing	A limited number of species, selected for a balance between speed of growth, suitability for location and quality of structural product are grown for a mixture of sawlogs and fibre. The material could be thinned, pruned or self pruning. While silvicultural input would be lower than growing for quality, the stands would still be managed to minimise growth stress and tension

	wood effects and thinned to increase log size. There would be opportunistic salvage of logs for fibre managed stands.
Assessment	Logs are batched for key characteristics, tagged and directed to the correct mill for processing.
Milling	Structural grade logs are cut for volume using an optimised multi-saw arrangement to economically produce the best structural product for the market. Probable appearance grade material would be batched off for particular drying attention.
Drying	Structural products are dried more quickly while maintaining stability and limiting unacceptable degrade, most likely unrecoverable collapse and excessive checking.
Product range	Range of products, primarily low cost structural product with a broader range of suitable niche structural composites.

Many Australian millers have moved away from this approach due to competition from softwood. However, increased optimisation, improved product differentiation and niche quality building markets may make it attractive. Internationally, a range of South American companies are pursuing this strategy.

10.4. Bridging between the current and possible future positions

For the solid wood products industry, the major issues to be addressed in moving from the current industry position to either of the scenarios above are log availability and improved production optimisation techniques.

Improved and increasing sawlog availability from plantations is critical to an industry seeking to profitably mill hardwood for solid products into the future. It is also probably critical for the forest growing industry. Both industries now seem to recognise this. The largest Australian hardwood sawn and decorative veneer producers are either also growing organisations or allied with them. Gunns Limited has broad plantation and hardwood milling and veneering interests. Neville Smith Timber Industries, a large hardwood miller operating in Victoria and Tasmania, has recently combined with Integrated Tree Cropping, a large plantation grower, while Boral Ltd, already a diversified hardwood and softwood producer, is looking to establish plantation hardwoods specifically for sawn product. From the growing end, Forest Enterprises Australia has recently established itself as a start-up sawn hardwood producer. While integration between the growing and milling sides of these businesses is just beginning, the longer term strategic approach is clear.

While these moves are encouraging, fundamental economic questions remain before large scale sawlog plantations are established. These include clarification of:

- potential values (and suitability) of the products from different sawlog management regimes
- the boundaries of silvicultural practices necessary to achieve those values
- the costs of operating within those boundaries
- the means to manage the physical and financial risk during the growth cycle.

Improved production optimisation techniques are necessary to reduce wastage, and decrease the cost of production for both the value and volume strategies. They are also necessary to assist industry cope with the plantation material supplied over the next 10 - 15 years that has not been grown specifically for sawlog.

11.0. Recommendations

The primary areas of research need are:

- determining the growing cost and value of logs grown specifically for high value solid wood products
- improved understanding of market structures, the impact of particular wood characteristics on product value and related economic aspects
- improved log availability modelling from the plantation and native forest estate
- increasing value from the current hardwood plantation resource by optimising processing to minimise degrade, especially during drying
- exploring the mechanisms and control of growth stress and tension wood effects
- refining understanding of the interactions of site, species and silviculture
- improvement of log output and quality through tree breeding.

Work in these areas should be deliberate, comparative studies, operating across species to a standard methodology that integrates growing and milling results, and provides improved assessment data for plantation inventory and economic modelling.

11.1. Detailed research recommendations

Products and markets

Better understandings of the solid hardwood market are needed to inform policy development and clarify production and breeding objectives. Research should seek to identify current consumption and likely future demand for solid hardwood products.

Alternative product markets

Only around 30% of the total merchantable volume from plantations managed for sawlog is pruned sawlogs. Research should seek to establish commercially feasible product options for the remainder and remove technical impediments to their use.

Log supply

The projected reduction in native forest sawlog supply is significantly greater than the projected availability of plantation grown sawlogs. Research should refine estimates of plantation area and expected log-grade outturn by management regime and site quality.

Processing for solid products

Harvesting and log grading

Harvested logs need to be graded effectively before despatch to mills. Also, damage needs to be controlled during storage and transport. Research should seek to determine methods of sorting logs to exploit within-stand variation and clarify log end split reduction and management practice.

Increasing value recovery from current hardwood plantations

Much of the plantation sawlog to be supplied over the next 10 - 15 years will not have been grown specifically for sawlog. Processing this material will present regular problems due to the high level of natural feature, the variability of wood properties and growth stress. Improved production optimisation techniques are necessary to reduce wastage and decrease the cost of processing this material. Research should seek to:

- improve sawing systems for quality. These can reduce processing costs, increase recovery and improve competitiveness
- minimise losses to tension wood/growth stress
- batch like material for processing, especially drying.

- develop processing quality control processes, such as non destructive evaluation of degrade, inline moisture content monitoring, and inline strength grading.

This research will also benefit processing regrowth native forest material.

Drying

Drying degrade leads to considerable loss of grade, value and recovery. It places considerable constraints on production speed, and therefore cost. Research should seek to trial novel drying methods. Projects in other areas should contain components that incorporate data collection and reporting on drying conditions and degrade. This will advance empirical understandings that should be combined with supporting theoretical work, especially in the areas of collapse and internal checking.

Control of growth stress and tension wood effects

Growth stress and tension wood effects lead to considerable loss of grade, value and recovery. Projects in other areas should contain components that incorporate data collection and reporting on growth stress and tension wood effects. This will advance empirical understanding that should be combined with supporting theoretical work.

Silviculture and genetics

Relatively high value eucalypt sawlogs can be grown in plantations. Improvements in the growing of sawlog producing plantations will be derived from:

- improvement in species selection. High-value within-species selections for solid wood utilisation may be different to selections for pulpwood crops. Selections for high solid-wood value should include revisitation of the 'which species' issue.
- improvement through tree breeding. Desirable heritable characteristics can be improved and undesirable ones minimized by breeding over the long term
- reviewing opportunities for clonal propagation. Trees in stands propagated from clones will be more uniform and therefore processing can be more efficient
- increased understanding of the interactions between site, species and silviculture so that productivity and log-grade outturn can be better predicted and optimized
- developing operational techniques to reduce the cost of pruning and the incidence of growth stresses.

Economics

Growing cost and value of logs specifically for solid wood products

It is essential that the primary economic questions about growing plantation hardwood specifically for solid wood products be clarified. This requires determining the value of products from high quality logs and the cost associated with growing and processing those logs. Research should seek to identify

- the value, recoveries and wood properties in sawn and peeled products from representative high value logs for a range of species on a range of sites
- the silvicultural regime necessary to grow those logs and their cost
- the sensitivity of wood quality, especially growth stress and drying aspects, to variation in silvicultural practice and site quality
- the suitability of the output for a range of end uses
- establishing means to recover a return from thinnings and other by-products.

The value of wood characteristics

Objectives for improved processing, silviculture, and genetics are framed to increase market value. Research should quantify the relative value of these characteristic and the increase in value through the material supply chain if they are improved.

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Glossary

Term	Description
Branch frequency	Branches, and the knots and grain deviation they are associated with, are major grade limiting characteristics.
Clear wood	Clear wood is wood that has a regular grain pattern and little or no natural feature, such as gum, knots or insect mark, on its visible surfaces. It is a critical aspect of demand for appearance products and to a lesser extent strength.
Collapse	Shrinkage due to collapse is distinguished from normal shrinkage by the fibres changing their shape (or collapsing) during drying. Collapse is visible in quartersawn boards as a ribbed 'wash board' appearance. In back-sawn material it shows as excessive shrinkage. Unrecovered collapse leads to a loss of grade.
Colour	Colour and colour consistency are critical aspects of visual appeal. However, in **AS 2796-1999**: Timber - Hardwood - Sawn and milled products, colour is held to be variable characteristic of the species.
Colour consistency	For solid timber, architectural demand is for a consistent colour, but there is broad demand for mixed tones. Veneer requires very consistent colour. The market for pale timbers is generally the most sensitive to colour variation.
Dbh	diameter at breast height of 1.3m (1.4m in New Zealand) - can be under-bark (UB) or over-bark (OB)
Decay	Decay is the decomposition of wood by fungus. Decay can occur in a log after pruning, branch shedding or insect damage.
Density	Density is the mass of wood substance and moisture enclosed within a piece divided by its volume, often expressed at a moisture content of 12%. Density correlates generally with strength, hardness, impact resistance and joint strength.
Durability	Durability in timber is its natural resistance to biodeterioration caused by fungi, insects and mechanical break down (e.g. weathering, checking and splitting). High durability is very desirable in applications exposed to the weather or likely insect attack, particularly termites.
End split	A defect that occurs when tensile stresses cause the wood fibres to separate and form cracks. Splits are cracks that extend through a piece. End splitting of boards and logs induced be growth stress leads to considerable loss of material in most stages of production.
Fire Performance	Timber used in bush fire prone areas, or in major commercial buildings must satisfy particular fire performance criteria.
Gluability	The ability to achieve particular quality of bond when glue is critical to use in many engineered wood products.
Grain	Grain is the direction, size, arrangement, appearance, or quality of the fibres in wood or timber. There are numerous combinations of grain and these have effect on visual appearance, mechanical strength, and workability.

Term	Description
Growth strain - growth stress	All eucalypts have longitudinal tensile growth stresses at the periphery of the stem. These stresses are generally at their maximum in the newly formed wood near the bark and decline in the older wood, producing a gradient in stress levels from the periphery to the centre of the stem. Young, tall, fast-grown trees can have considerable radial growth strain gradients presenting severe problems affecting wood quality. They can affect yield, product dimensions and level of distortion during sawing of logs.
Gum Vein - Kino	Gum, also called kino, is a natural exudation produced in trees as a result of fire or mechanical damage. A gum vein or kino vein is a ribbon of gum between growth rings. The quantity of gum or kino pockets is limited in the most high value appearance products and its presence leads to a downgrade of sawn boards and veneer. It is also undesirable in the manufacture of composites.
Hardness	Hardness is a property of wood that enables it to resist indentation. It is often determined by the Janka hardness test. A particular level of hardness is required for any timber subject to wear.
Heart / Corewood diameter	The heart, also known as the core wood or inner heart, is the wood adjacent to and including the pith that is within 50 mm of the centre of the pith. In hardwoods this material has lower density, strength and durability than the surrounding heartwood. It is generally removed during sawing.
heartwood content	Heartwood is the mature inner zone of the tree. It is usually darker than sapwood because its cells contain tannins and other substances deposited when the heartwood was formed. It provides the most durable and consistent timber.
Insect feature	Insect feature, the marks left in the wood by insect or termite damage, is a major grade-limiting defects in many solid eucalypt products.
Internal checking	In timber, separation of the fibres in the interior of the piece, usually in the radial direction. The checks are often not visible on the surfaces and may not be visible on a cut section. Internal checks are irrecoverable degrade.
IRR	Internal Rate of Return
Joint Group	For the purpose of joint design under AS 1720.1, all species have been classified into six joint groups when unseasoned and six others when seasoned. Joint groups can also be established in relationship to the wood's density.
Knots	A knot is a portion of a branch or limb that has been surrounded by subsequent growth of the stem. Knots are major grade-limiting defects in structural and appearance timber and veneer.
Knotty core diameter	The size of the internal core of knotty wood after pruning affects the recovery of appearance and higher grade structural material from the log.

Term	Description
Log form - stem taper	The greater the amount of taper in a log, the less volume of usable material recovered from it.
Lyctus resistant sapwood	The sapwood of many Australian hardwoods is susceptible to attack by the lyctid borer, a small wood-eating beetle that infect starch rich sapwood of some hardwood timbers.
Mean annual increment (MAI)	Usually describes volume - cubic metres per hectare per year - MAI_{10} is MAI at age 10 years, maximum MAI is also often reported.
microfibril angle (MFA)	microfibril angle in the cell-wall
NPV	Net Present Value
OD	oven dried at 103°C
Preservative retention	Timber is treated with chemicals to protect it against insect or fungal attack during drying or in its service life. The type of chemicals, the concentration retained within the piece and its penetration into the wood determines the level of protection against specific biological hazards.
Pruning	Removing the branches from the lower part of the tree trunk so that subsequent bole growth is free of knots.
Sapwood thickness - (mm)	This zone, immediately under the cambium, is composed of living cells that take water and mineral salts from the roots to the leaves. Sapwood is usually lighter in colour than the heartwood. While stronger than heartwood, the sapwood is more susceptible to insect attack and less durable.
Shrinkage	Shrinkage is the contraction of wood fibres caused by drying. Timber shrinks in three principle directions. Longitudinal shrinkage is along the grain. Radial shrinkage is across the grain, at right angles to the growth rings direction or across the wide face of a perfectly quarter sawn board. Tangential shrinkage is across the grain at a tangent to the growth or across the wide face of a perfectly back sawn board.
Shrinkage ratio - tangential/radial	The amount of shrinkage in each direction and the ratio of tangential to radial shrinkage for a species can affect recovery, drying degrade and stability of a species in production and service.
Silviculture	The science and technology of managing forest establishment, composition and growth. In plantation forestry, the key elements of silviculture include: • selecting the tree species suitable for the management objectives and site • the establishment and tending methods used • the initial stocking (number of trees planted per unit area) • the number, timing and extent of thinning and pruning operations A combination of these elements applied to a particular plantation is referred to as a 'silvicultural regime'.

Term	Description
Site quality	In timber production terms, the rating of the site for growth of timber products
sph	Stems per hectare
Stability	The stability of the piece after moulding and in use is critical to use in high value appearance products
Stiffness	The modulus of elasticity is a fundamental material constant and is an index of the stiffness of the material. It is a major component in determining a strength group for timber.
Strength	Strength or modulus of rupture is another material constant and is the stress at which a material fails in either tension or compression. It is another major component in determining a strength group for timber.
Surface checking	A separation of fibres along the grain forming a fissure, but not extending through the piece from face to face. Checks commonly result from stresses built up during seasoning. They tend to run radially, across the growth rings. Checks are limited in appearance products.
Tension wood	Tension wood forms at the cambium in response to the development of high internal bending stresses within trees. Typically, tension wood forms on the upper side of leaning stems and branches to correct tree alignment and may also form where trees realign their crowns towards available light. However, unlike native forest trees, in plantation-grown eucalypts tension wood is also common in straight, vertical stems and dominant trees. In these circumstances wind exposure is thought to be a contributing factor to its formation. Tension wood produces very high growth stresses and abnormal shrinkage in wood during drying. Where it occurs it is a barrier to efficient processing and recoveries and product quality can be restricted.
Thinning	Removing a proportion of the trees in a stand so that remaining trees have more growing space.
Workability Machining	The quality of surface and arrises after planning, drilling and finishing is critical to use in high value appearance products

Appendix 1: Species names and description

Botanical Name	Common Name	Description
Corymbia (C.) maculata	Spotted Gum	Medium to large hardwood found from South East Queensland to South East NSW.
C. citriodora		Medium to large hardwood found from coastal to South East Queensland and west of Townsville to the Atherton Tableland
Eucalyptus (E.) camuldulensis	Red River Gum	Medium to large hardwood found adjacent to most of the inland rivers of mainland Australia. Can stand long periods of flood.
E. cladocalyx	Sugar Gum	Large hardwood found in South Australia from the southern Flinders Ranges and Eyre Peninsula to Kangaroo Island
E. cloeziana	Gympie Messate	Large hardwood of scattered occurrence in coastal Queensland from Gympie to the Atherton district.
E. delegatensis	Tasmanian Oak, Victorian Ash	Large hardwood of the cold climate areas of Tasmania, eastern Victoria and south eastern NSW.
E. dunnii	Dunn's White Gum	Large hardwood of the richer soils adjacent to the rainforests of the far north coast and coastal ranges of NSW and southern Queensland.
E. fastigata	Brownbarrel	Large hardwood of the north-east corner of Victoria & table-land districts/south coast of NSW. Pale sapwood & medium and even texture.
E. globulus	Southern Blue Gum	Large hardwood of the cooler districts of south-eastern Australia, mainly in Victoria and Tasmania.
E. marginata	Jarrah	Large hardwood of the south-west corner of Western Australia
E. microcorys	Tallowwood	Large hardwood of the coast and coastal ranges between the Hunter River in NSW and the Maryborough district of Queensland.
E. nitens;	Shining Gum	Large hardwood of the high altitude country on both sides of the Victoria – NSW border and the mountain areas of eastern Victoria.
E. obliqua.	Messmate,	Large hardwood of common occurrence in Tasmania and Victoria and also in the tableland districts of NSW and southern Queensland.
E. pilularis;	Blackbutt,	Large hardwood of coastal forests between Bega, NSW and Maryborough, Queensland

Botanical Name	Common Name	Description
E. regnans	Tasmanian Oak, Victorian Ash	Very large hardwood of the mountainous regions of eastern Victoria.
E. saligna;	Sydney Blue Gum,	Large commonly occurring hardwood of the east coast of Australia, from Bateman's bay, NSW to southern Queensland.
E. sieberi	Silvertop Ash (Ironbark in Tasmania)	Large hardwood of the southern and central coast, tablelands of NSW and eastern Victoria and a restricted coastal belt in the East of Tasmania.
E. sideroxylon	Red Iron Bark	Medium to large tree occurring in north central Victoria, inland slopes of NSW and occasionally in coastal districts of Victoria, NSW and Queensland. Dark red hardwood, pale yellow sapwood. Medium and even texture
Syncarpia glomulifera	Turpentine	Large hardwood found on the east coast between Sydney and Cairns.

Appendix 2: Practitioners interviewed

Table A 2.1: Industry members interviewed, 2004

Person	Organisation	State
Jugo Ilic	ensis – a joint force of CSIRO and Forest Research	International
Jun Li Yang	ensis - a joint force of CSIRO and Forest Research	International
Silvia Pongracic	ensis - a joint force of CSIRO and Forest Research	International
Stuart Austin	Big River Timbers Pty Ltd	NSW
Paul Dickman	Boral Ltd	NSW
Steve Worley	Boral Ltd	NSW
Trevor Bailey	Notaras Timber	NSW
Bill Joe	State Forests NSW	NSW
Geoff Smith	State Forests NSW	NSW
Michael Henson	State Forests NSW	NSW
Peter Paunovic	State Forests NSW	NSW
Robin Heathcote	State Forests NSW	NSW
Bill Leggate	DPIF Queensland	Qld
Andy McNaught	Plywood Association of Australia	Qld
Steve Martini	Forest Enterprises Australia	Tasmania
Bob Gordon	Forestry Tasmania	Tasmania
Peter Volker	Forestry Tasmania	Tasmania
Geoff Eberhardt	Gunns Ltd	Tasmania
Ian Blandin	Gunns Ltd	Tasmania
Brendan Green & Neil Burgess	Drouin West Timber	Victoria
Steve Elms	Hancock Victorian Plantations Pty Ltd	Victoria
Tom Baker	University of Melbourne / DSE	Victoria
Ken Last	Neville Smith Industries Pty Ltd	Victoria

Appendix 3: Summary of reported species information

Variation between species - summary of information compiled by species where available - wood properties largely reported in Appendix 4.

Species summary		E. camaldulensis	E. cloeziana	E. delegatensis	E. dunnii	E. globulus	E. grandis	E. maculata C. maculata	E. nitens	E. obliqua	E. pilularis	E. regnans	E. sideroxylon	P. radiata	information source
common name		river red gum		alpine ash		southern blue gum	flooded gum (rose gum?)	spotted gum	shining gum	messmate	blackbutt	mountain ash	red ironbark		
Natural durability ratings	Lyctid susceptibility of sapwood					suscep.		suscep.	suscep.		not suscep.	not suscep.	suscep.	not suscep.	Tepper (2002)
	Termite resistance of heartwood							resistant			resistant	not resistant	resistant	not resistant	
	Natural durability class of heartwood: in ground contact					3		2	4		2	4	1	4	
	Natural durability class of heartwood: outside above ground					3		1	3		1	4	1	4	
suitability for	round timbers	**				*	**	***	*			*		*	Waugh (1996)
	sawn appearance (furniture)	*				*	**	**	**			*		*	*** = very good
	sawn engineering	**				***	**	***	*			*		*	** = good
	engineering veneer	n.s.				*	***	**	**			**		*	* = accep.
	fibre composites	n.s.				**	**	*	**			**		***	? = no reliable data
	pulp and paper	n.s.				***	**	**	**			**		***	n.s. = unaccep.
average number of internal checks by age	15-20 years					0.9	0		0.9			9.1			Waugh (1996)
	21-25 years					0.5	0		2.6			7.6			
	30-35 years					0.4			6.2*			3.2			* reaction-wood in outer rings
self-pruning							good		poor			poor			Waugh (1996)
suitability for moulding (fraction	standard moulding tool	0%				9%	38%	23%					50%		Ozarska and Ashley (1998) - . 16
	system tool with chip breaker	0%				50%	0%	100%					50%		
Relative attributes of major eucalypt species available for plantations	Ease of propagation			2		2			2a	1		2			Neilsen (1990) cited by Wood et al (in prep) . 2
	Growth rate potential			1		3		.	3	2		3			
	Response to low fertility			1		2			1	1		0			
	Frost tolerance			3		0			3	2		2			0-3 performance rating; 0 unsatisfactory, 1 poor, 2 satisfactory and 3 very good.
	Drought tolerance			1		3			2	2		1			
	Resistance to water logging			0		1			1	0		0			
	Insect resistance			1		2			1b	1		0			apaper-pot seedlings much easier than open-root, blong term effects still to be determined, cyoung trees may be sui. though yet to be verified, dnot yet verified
	Browsing resistance			2		1			1	2		1			
	Branch shedding			2		3			1	2		2			
	Solid wood quality			2		1c			2	3		3			
	Plantation suitability			N		Y			Yd	Yd		Yd			
Boral established flooring market for natural stand wood				flooring				flooring			flooring				Boral web page
wood and pulp properties at Gympie site	basic density		644		534			642			590				Hicks and Clark 2001
	screened kraft pulp yield		50.1		51.6			52.1			50.9				
	fibre length		0.9		0.86			0.84			0.88				
	tear at 250ml CSF		10.6		9.9			9.9			10.6				
	tensile at 250ml CSF		87		102			107			99				
Growth relative to mean of tested species - 5 sites, Gippsland, Victoria	Mt Worth East			41%	0%	41%	-51%		143%	-66%		14%			Duncan et al. 2000
	Delburn			-23%	-30%	50%	0%		34%	-14%		27%			
	Stockdale			-75%	-47%	56%	-1%		-7%	10%		20%			
	Flynns Creek			-70%	-62%	120%	20%		83%	-26%		-37%			
	Stradbroke			-44%	-70%	8%	77%		-10%	9%		-17%			
Mundubbera	Relative productivity species mean		-78%		305%						-70%				
	Relative survival species mean		-15%		15%						-11%				
Mt Binga	Relative productivity species mean		-67%		403%						-52%				
	Relative survival mean within species		-12%		21%						6%				
Mt Gambia	Relative Growth mean at 18 months	-69%	-86%	30%	49%	234%	16%		152%	26%	-69%	86%			Bird, P. R. (2000)
	Relative Growth mean at 4 years			-18%	-22%	55%			44%	-27%		-2%			
Form pruned trees	Growth relative to sample mean	7%					110%						-8%		Bird (2000) - . 7.7, p.115
	Percentage of trees sui. for timber	40%					100%						50%		
Unpruned trees	Growth relative to sample mean	-3%					70%						13%		
	Percentage of trees sui. for timber	11%					38%						47%		
species growing in South Western Victoria	Preferred rain (mm)	600+				900+	1000+	800+	1000+	800+				800+	Bird (2000) - . 7.6 and 7.7, p.114-115
	Min. rain (mm)	500				700	700	500	700	600				500	
	Preferred position	alluvial plain				cool valley	alluvial flat	valley/slope	cool wet slope	cool wet slope				slope	
	Preferred soil type for optimal growth	moist sandy loam over clay				heavy loam-clay	heavy loam	sandy clay	clay-loam	mod fertile gravelly loam				sandy loam over clay	
	Prohibitive conditions for survival or good growth	deep sand/shallow w/stone				dry sites, shallow soil	heavy clay	wet/heavy clay	dry sites, shallow soils	wet clay/acid sand				fire, wet/heavy clay	
	Tolerance of poor drainage	high				moderate	low	low	high	moderate				low	
	Tolerance of soil salinity	high				low	low	low-mod	low	low				low	
	Tolerance of dry site	low				v. low	v. low	moderate	v. low	low				moderate	
	Tolerance to exposure	moderate				moderate	moderate	high	high (cold)	low				high	
	Form when open-grown	poor				good	moderate		good	moderate				moderate	
	Culling ratio for good form	high				low	low		low	moderate				low-high	
	Frost resistance	high				mod	low-mod	low	v. high	high				v. high	
	Pest problems	S				S,A,B			S,A					D	
	Durable class	2, 2				3, 4	3, 3	2, 2	4	4, 4				4, 4	
	Borer susc.	S				S	R	S	S	S				I	
	Strength & stress (12% mc)	SD5, F8-17				SD2, F 17-34	SD4	SD2, F 17-34	SD4, F 11-22	SD3, F14-27				SD6, F5-14	
	Strength & stress (green)	S5, F4-11				S3, F8-17	S3	S2, F11-22	S4, F7-14	S3, F8-17				S6	
	Hardness (green, dry)	6.8,9.6				7.3,11.4	5.5,7.3	8.8,10.1	4.6,5.8	5.3,7.2				2.1,3.3	
	Density (green, 12%mc)	1100, 900				1150, 950	1100, 750	1200, 1000	1100, 650	1100, 750				800, 550	
	Shrinkage % (rad., tang.)	4.4, 8.9				6, 7.7	4, 7.5	4.5, 6.1	5, 9.4	5, 11.3				-, 5.1	
	Stability % (rad., tang.)	0.22, 0.31				0.28, 0.40	-, 0.30	0.32, 0.38	-, 0.33	0.23, 0.36				0.20, 0.27	
	Drying	A, S, FL				C, R	A	A	C, W, R	S, C, R				A	
	Colour	Red				L Tan	P-Str	L Br	P-Str	Br-Str					
	Grain type	1, 13				F	S	1, W, D		17, 13					
	Surface	D, P				W	P	W		W, P					
	Firwd., pulp, C	F				P	F,P		P	F					

Appendix 4: Summary of reported wood properties

Table 4.1 Part A - Reported wood properties

species	age	where	Annual Rainfall (mm)	number of trees	dbhob -mean (cm)	green density mean (kg/m3)	basic density mean (kg/m3)	air-dry density mean (kg/m3)	green bending MOE mean (MPa)	green bending MOR mean (MPa)	dry (12%MC) bending MOE mean (MPa)	dry (12%MC) bending MOR mean (MPa)	dry (12%MC) hardness Janka mean (kN)	strength group	tangential shrinkage mean - green to 12% BEFORE reconditioning	radial shrinkage mean - green to 12% BEFORE reconditioning	tangential shrinkage mean green to 12% including reconditioning	radial shrinkage mean - green to 12% including reconditioning	source of information
C. citriodora	41	Gatton (SWQ)	800	22	20.6		802								5.8%	3.4%			Leggate et al 2000
C. citriodora	native forest						740								-6.1%	-4.3%			Leggate et al 2000
C. maculata	18	Mildura, (Victoria)					797				14.1	118							Ashley and Ozarska (2000)
C. maculata	28	Shepparton, (Victoria)					888				17	141							Ashley and Ozarska (2000)
C. maculata	40	Lake Hume					870				15.2	131							Ashley and Ozarska (2000)
C. maculata	native forest						969				19	142							Ashley and Ozarska (2000)
E. argophloia	32	Dalby (SWQc)	690	3			815								4.9%	2.8%			Leggate et al 2000
E. camaldulensis	17	Mildura, (Victoria)					778				11.4	92.1							Ashley and Ozarska (2000)
E. camaldulensis	native forest						854				11	101							Ashley and Ozarska (2000)
E. camuldulensis		Sichuan, China					490	660		44	9.2	86			0.0522	0.0342			Jiang, Lu, Yin and Luo (2000)
E. camuldulensis		Guangxi, China					600	800		60	12.6	101			0.0522	0.0378			Jiang, Lu, Yin and Luo (2000)
E. citriodora		Guangxi, China					770	970		63	18.6	142			0.0702	0.0576			Jiang, Lu, Yin and Luo (2000)
E. cladocalyx	40	Earlston, (Victoria)					1032				17.4	137.8							Ashley and Ozarska (2000)
E. cladocalyx	native forest						1035				17	132							Ashley and Ozarska (2000)
E. cloeziana	32	Pomona (SEQa)	1500	15	38.3		769								7.0%	5.1%			Leggate et al 2000
E. cloeziana	35	Pomona (SEQ)	1500	17	40.9		782								5.9%	4.2%			Leggate et al 2000
E. cloeziana	?				23.2		609				11.9	109							Muneri, Leggate and Palmer (1999)
E. cloeziana	native forest						810								-6.2%	-3.4%			Leggate et al 2000
E. dunnii	6	Moonmerri SF, NSW				1074	442		8185	53.7	10	75	3.6		10.20%	3.20%	6.20%	2.20%	Joe, B. SF NSW - presentation
E. dunnii	9	Newry SF, Coffs Harbour		33	23.8	1087	508				13.9	104	4.52						Dickson et al 2003
E. dunnii	25	Newry SF, Coffs Harbour		34	39.8	1147	600				15.5	124	6.3						Dickson et al 2003
E. dunnii	25?	?										120							Joe, B. SF NSW - presentation
E. dunnii	9?	?										100							Joe, B. SF NSW - presentation
E. globulus	4.5	Manjimup, W.A. - cores		39			464												Greaves and Dutkowski (2003)
E. globulus	7.5	Manjimup, W.A. - cores		30			511												Greaves and Dutkowski (2003)
E. globulus	7.5	Manjimup, W.A. - cores		30			498												Greaves and Dutkowski (2003)
E. globulus	7.5	Albany, W.A. - cores		40			479												Greaves and Dutkowski (2003)
E. globulus	7.5	Albany, W.A. - cores		23			477												Greaves and Dutkowski (2003)
E. globulus	7.5	Albany, W.A. - cores		30			468												Greaves and Dutkowski (2003)
E. globulus	10	Mt Gambier		59			698		9400		22.4								Yang and Ilic 2003?
E. globulus	10	Australia					533												Perez 1999
E. globulus	10.5	Gippsland, Victoria - cores		39			519												Greaves and Dutkowski (2003)
E. globulus	10.5	Gippsland, Victoria - cores		30			549												Greaves and Dutkowski (2003)
E. globulus	10.5	Gippsland, Victoria - cores		30			542												Greaves and Dutkowski (2003)
E. globulus	13					1041	538	737									6.9%	8.5%	Hingston, B. (2000)
E. globulus	15	Alexandria, (Victoria)					703.2				9.8	87.9							Ashley and Ozarska (2000)
E. globulus	15	Oxley, (Victoria)					728.1				13.3	105							Ashley and Ozarska (2000)
E. globulus	19	Burnie, Tas					554												Yang and Waugh 1996a
E. globulus	21	Burnie, Tas					604												Yang and Waugh 1996a
E. globulus	33	Burnie, Tas					604												Yang and Waugh 1996a
E. globulus	native forest						843				20	146							Ashley and Ozarska (2000)
E. globulus																	estimate		Washusen 2000 (26th FP Conf)
E. grandis	22	Shepparton, (Victoria)					720.9				12.3	78.2							Ashley and Ozarska (2000)
E. grandis	28	Macksville, (New South Wales)					690.7				13.5	98.2							Ashley and Ozarska (2000)
E. grandis	28	Ravenshoe (NQ)	1669	11	26.7		568								5.9%	3.4%			Leggate et al 2000
E. grandis	native forest						751				16	119							Ashley and Ozarska (2000)
E. grandis	native forest						510								-7.2%	-4.0%			Leggate et al 2000
E. microcorys	28	Ravenshoe (NQb)	1669	22	25.5		729								5.6%	3.5%			Leggate et al 2000
E. microcorys	native forest						800								-6.1%	-3.7%			Leggate et al 2000
E. nitens	4	Chile					459.3												Rojas et al. 1993b
E. nitens	6	South Africa - Shafton					489												Clarke 2000
E. nitens	6	South Africa - Helvetia					555												Clarke 2000
E. nitens	7	Chile					458.4												Rojas et al. 1993b
E. nitens	8						440						4		6.33	2.37			Chafe, S. C. (1985)
E. nitens	8	Chile					457.4												Rojas et al. 1993b
E. nitens	8	Chile					457												FAMASA (no publish date)
E. nitens	8.5	Britannia Creek, Victoria					451												McKimm 1985 (I and II)
E. nitens	8.5	Chile					480												McKim & Ilic 1997
E. nitens	9	Chile					434												Omme 1992
E. nitens	10	Australia					483												Perez 1999
E. nitens	11.5	Chile					512												Purnell 1988
E. nitens	15	Burnie, Tas					460							SD6					Yang and Waugh 1996b
E. nitens	15	New Zealand					390-556												Perez 1999
E. nitens	24	Burnie, Tas					478							SD6					Yang and Waugh 1996b
E. nitens	29	Mt Beenak, Vic					554							SD5					Yang and Waugh 1996b
E. nitens	native forest													SD4					
E. nitens																	estimate		Washusen 2000 (26th FP Conf)
E. nitens									8150	55-74	10-13	84-117							Prado et al. 1989
E. pilularis	4	Dandah, NW NSW	1800	15	16.9						8.8	77							Muneri and Leggate (2000)
E. pilularis	4	Harcourt, NW NSW	1800	11	15.9		463				9.5	82.9	4		6.99	2.23			Muneri and Leggate (2000)
E. pilularis	21	Bellthorpe (SEQ)	1688	40	39.2		567												Leggate et al 2000
E. pilularis	native forest						710												Leggate et al 2000
E. regnans	15	Jeeriang, Vic					442							SD6					reference ???
E. regnans	22	Jumbuck, Vic					442							SD6					reference ???
E. regnans	30	Ashtakoff, Vic					492							SD5					reference ???
E. regnans	native forest													SD3					reference ???
E. regnans	ve forest regrowth													SD4					reference ???
E. robusta		Sichuan, China					500	600		39	10.2	71			0.0504	0.0288			Jiang, Lu, Yin and Luo (2000)
E. robusta		Guangxi, China					550	700		52	12.3	91			0.054	0.0378			Jiang, Lu, Yin and Luo (2000)
E. rudis		Guangxi, China					490	630		46	12	94			0.0558	0.0378			Jiang, Lu, Yin and Luo (2000)
E. saligna	0	Shepparton, (Victoria)					779.4				14.4	99.4							Ashley and Ozarska (2000)
E. saligna	18	Mildura, (Victoria)					774.3				14.7	116							Ashley and Ozarska (2000)
E. saligna	native forest						806				15	122							Ashley and Ozarska (2000)
E. sideroxylon	40	Lake Hume, (Vic/N.S.W. border)					933.6				10.4	94.4							Ashley and Ozarska (2000)
E. sideroxylon	native forest						1060				17	148							Ashley and Ozarska (2000)

Table 4.1 Part B - Reported wood properties

species	age	where	Annual Rainfall (mm)	number of trees	heartwood content mean	sapwood thickness - mean (mm)	lowest dead branch height (m)	lowest green branch height (m)	branch frequency	stem taper	growth strain	end split	microfibril angle (degrees)	% Lignina	% Alchohol	% Holocellulose	% Alpha cellulose	Fibre perimeter (mm)	Length of fibre (mm)	Width of fibre	Coarseness (mg/100m)	source of information
C. citriodora	41	Gatton (SWQ)	800	22		29																Leggate et al 2000
C. citriodora	native forest					(15–25)																Leggate et al 2000
E. argophloia	32	Dalby (SWQc)	690	3		18																Leggate et al 2000
E. argophloia	native forest					(15–25)																Leggate et al 2000
E. cloeziana	32	Pomona (SEQa)	1500	15		19																Leggate et al 2000
E. cloeziana	35	Pomona (SEQ)	1500	17		18																Leggate et al 2000
E. cloeziana	?				61%	21					info	info										Muneri, Leggate and Palmer (1999)
E. cloeziana	native forest					(15–25)																Leggate et al 2000
E. dunnii	6	Moonmerri SF, NSW			43%																	Joe, B. SF NSW - presentation
E. dunnii	9	Newry SF, Coffs Harbour		33	41%								-									Dickson et al 2003
E. dunnii	25	Newry SF, Coffs Harbour		34	61%								12.8									Dickson et al 2003
E. globulus	8	Chile												23	1.4	82.6			0.83		4.1	Perez 1999
E. globulus	10	Mt Gambier		59							info											Yang and Ilic 2003?
E. globulus	10	Australia																	0.93	0.2	7	Perez 1999
E. globulus	10	Australia												27								Perez 1999
E. globulus	14	Chile												19.7	1	85.2			1		7.6	Perez 1999
E. globulus	19	Burnie, Tas					11.1	8.9														Yang and Waugh 1996a
E. globulus	19	Chile												20.4	1.3	83.7			0.91		8	Perez 1999
E. globulus	21	Burnie, Tas					12.1	15.6														Yang and Waugh 1996a
E. globulus	33	Burnie, Tas					20.4	21.4														Yang and Waugh 1996a
E. globulus	10-13	Chile												21		81	56.2		0.95	0.2		Perez 1999
E. grandis	28	Ravenshoe (NQ)	1669	11		26																Leggate et al 2000
E. grandis	3-8	South Africa										info										Verryn, Snedden and Malan 2000
E. grandis	native forest					(15-25)																Leggate et al 2000
E. microcorys	28	Ravenshoe (NQb)	1669	22		23																Leggate et al 2000
E. microcorys	native forest					(15-25)																Leggate et al 2000
E. nitens	6	Chile																19-21.6	0.87		4.9	Perez 1999
E. nitens	8	Chile																	0.88			Perez 1999
E. nitens	8.5	Britannia Creek, Victoria			47%	35			31	0.90%	info											McKimm 1985 (I and II)
E. nitens	9	Chile														73	22.4		0.97		6.7	Perez 1999
E. nitens	10	Australia																19-21.6	0.97	0.2	6.4	Perez 1999
E. nitens	10	Chile														74.7-78	23.5-24.8					Perez 1999
E. nitens	14	Chile													1.8	82.6	21.7		0.9		7.1	Perez 1999
E. nitens	15	Burnie, Tas					6.6	12.3														Yang and Waugh 1996b
E. nitens	15	New Zealand												25.1-29.7					0.78-0.95			Perez 1999
E. nitens	16	Chile													1.8	83.9	21.5		0.79		6.7	Perez 1999
E. nitens	24	Burnie, Tas					6.7	12.2														Yang and Waugh 1996b
E. nitens	29	Mt Beenak, Vic					15	23.3														Yang and Waugh 1996b
E. pilularis	4	Dandahl, NW NSW	1800	15							info											Muneri and Leggate (2000)
E. pilularis	4	Harcourt, NW NSW	1800	11							info											Muneri and Leggate (2000)
E. pilularis	21	Belthorpe (SEQ)	1688	40		22																Leggate et al 2000
E. pilularis	36	Cpt. 54. mid-north coast NSW										info										Muneri et al 2003
E. pilularis	native forest					(15–25)																Leggate et al 2000
E. regnans	15	Jeeralang, Vic					8.3	13.8														reference ???
E. regnans	22	Jumbuck, Vic					16.7	22.8														reference ???
E. regnans	30	Ashleakoff, Vic					16.1	19.5														reference ???

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Pisa, November 23, 2009

VIA TELEFAX
001-703-837-0980

URGENT DEADLINE:
November 28, 2009

To the Kind attention of Mr. Ira Schultz

Re: New US national phase of International Patent Application No. PCT/IB2008/001337, "**RESIDUAL CURRENT CIRCUIT BREAKER CONTROLLING AND AUXILIARY APPARATUS, AND RESIDUAL CURRENT CIRCUIT BREAKER EQUIPPED THEREBY**" in the name of PIERI Giovanni.
your ref.: --
our ref.: B40/0142

Dear Ira,
You are kindly requested to take all necessary steps for entering the national phase in the USA of the above referenced International Application. Please, note that the deadline is November 28, 2009.

Please, note that we have submitted some amendments to the claims under Art. 19 PCT. The new set of claims has been published as WO2008146135A4.

We are sending by an e-mail message the amended claims both in clean copy and with amendments highlighted, together with:

⇒ a copy of the application as filed in editable format;
⇒ a copy of the amended claims filed under Art. 19 PCT in editable format;
⇒ a copy of the International Search Report;
⇒ a copy of the Drawings;

Please, confirm whether you can file the application by the deadline in USA and inform us about any missing documentation you require.

Please acknowledge receipt of this letter.

With Best Regards
AGENZIA BREVETTI & MARCHI
Francesco de Milato

Encl.

FdM/gf

ABM

DENNISON, SCHULTZ
& MACDONALD

FILING INSTRUCTIONS

OUR REFERENCE:	B40/0142
COUNTRY:	USA
KIND OF PROTECTION:	PATENT
CRITICAL DATE:	November 28, 2009
TITLE:	RESIDUAL CURRENT CIRCUIT BREAKER CONTROLLING AND AUXILIARY APPARATUS, AND RESIDUAL CURRENT CIRCUIT BREAKER EQUIPPED THEREBY
APPLICANT and INVENTOR:	PIERI Giovanni Via Leonardo da Vinci, 20 55049 – Viareggio (LU) ITALY
ORIGIN:	PCT/IB2008/001337 of April 12, 2007
PRIORITY CLAIMED:	IT LU2007A000011 dated May 28, 2007
EXAMINATION:	The International Search Report issued by the European Patent Office is enclosed.
NOTES	1. An amended set of claims has been filed under Art. 19 PCT 2. Since the prescribed margins have not been applied, the number of the figures has been "cut" in the Application as published. Please, file the attached sheets of drawings as preliminary amendments.